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Evaluation of Deep Shaft Biological Wastewater Treatment Process at Ithaca, New York

Stearns and Wheler
Cazenovia, NY

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Donald E. Schwinn   Robert Butterworth
Donald F. Storrier

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STEARNS & WHELER
Engineers and Scientists
10 Albany Street
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16. ABSTRACT

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Performance of the Deep Shaft process was evaluated under a variety of operating conditions including raw wastewater and primary effluent as influent sources, constant and diurnal (varying) flow patterns, with and without polymer addition as a flotation aid, and with alum addition for a short period for phosphorus removal. Pilot plant influent characteristics were not typical of domestic raw wastewater or primary effluent as had been anticipated in selecting Ithaca as the project site as a result of the practice of returning partially ground screenings and abnormally strong anaerobic digester supernatant to the main plant headworks. Numerous operational problems were also encountered that hindered the experimental program; however, sufficient data were obtained to reach the following conclusions:

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2. Effluent concentrations of BOD_5 and suspended solids averaged 20 mg/l and 27 mg/l, respectively, and percent removals across the Deep Shaft process (neglecting removals that occurred in the main plant's degritting unit) were 80 and 88 percent, respectively, for those periods when a routine operation was established while treating raw wastewater. Effluent BOD_5 values for the warmest weather periods may reflect some nitrogenous oxygen demand, as partial nitrification was, unexpectedly, evidenced during these periods.
3. The process appeared more effective in treating raw wastewater than primary effluent and more effective under constant flow operation than diurnal flow operation.
4. Polymer addition increased the quantity of float blanket but did not significantly improve effluent quality, while alum addition adversely affected the float blanket when treating primary effluent over a short time period.

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EVALUATION OF DEEP SHAFT BIOLOGICAL WASTEWATER TREATMENT PROCESS AT ITHACA, NEW YORK

by

Donald E. Schwinn
Donald F. Storrier
Robert Butterworth
Stearns & Wheler, Engineers and Scientists
Cazenovia, New York 13035

Cooperative Agreement No. CS806081

Project Officer

Richard C. Brenner
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

The innovative and alternative technology provisions of the Clean Water Act of 1977 (PL 95-217) provide financial incentives to communities that use wastewater treatment alternatives that reduce costs or energy consumption over conventional systems. Some of these technologies have been only recently developed and are not in widespread use in this country. The work reported herein evaluates the feasibility of the Deep Shaft Biological Wastewater Treatment Process and its application in the United States for the treatment of municipal wastewater.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The major objectives of this study were to demonstrate the feasibility of the Deep Shaft biological treatment process and to evaluate its application for the treatment of municipal wastewater. A 757-m^3/day (0.2-mgd) pilot plant facility was constructed at the existing wastewater treatment plant site in Ithaca, New York, for this purpose.

Performance of the Deep Shaft process was evaluated under a variety of operating conditions including raw wastewater and primary effluent as influent sources, constant and diurnal (varying) flow patterns, with and without polymer addition as a flotation aid, and with alum addition for a short period for phosphorus removal. Pilot plant influent characteristics were not typical of domestic raw wastewater or primary effluent as had been anticipated in selecting Ithaca as the project site as a result of the practice of returning partially ground screenings and abnormally strong anaerobic digester supernatant to the main plant headworks. Numerous operational problems were also encountered that hindered the experimental program; however, sufficient data were obtained to reach the following conclusions:

1. The Deep Shaft process is a high-rate activated sludge process utilizing flotation for solids separation. F/M loadings were in the range of 0.5-1.0 kg BOD_5/day/kg MLVSS, SRT values were 1-4 days, and bioreactor HRT values were 45-53 min exclusive of recycle flows.

2. Effluent concentrations of BOD_5 and suspended solids averaged 20 and 27 mg/l, respectively, and percent removals across the Deep Shaft process (neglecting removals that occurred in the main plant's degritting unit) were 80 and 88 percent, respectively, for those periods when a routine operation was established while treating raw wastewater. Effluent BOD_5 values for the warmest weather periods may reflect some nitrogenous oxygen demand as partial nitrification unexpectedly occurred during these periods.

3. The process appeared more effective in treating raw wastewater than primary effluent and more effective under constant flow operation than diurnal flow operation.

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This report was submitted in fulfillment of Cooperative Agreement No. CS806081 by the City of Ithaca, New York, under the partial sponsorship of the United States Environmental Protection Agency. The experimental work was conducted from October 1979 to August 1981 under the direction of Stearns & Wheler, Engineers and Scientists, who served as subcontractor to the City of Ithaca.

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Advice and assistance were provided during the course of this study by Mr. Richard C. Brenner, Project Officer for the U.S. Environmental Protection Agency.

Process technology and operations advice were provided by the staff of Eco Technology, C-I-L Inc. under the direction of Mr. David C. Pollock, Vice President.

SECTION 1

INTRODUCTION

The Deep Shaft process is a high-rate, high-intensity, high-oxygen-transfer biological treatment process for the purification of domestic or biodegradable industrial wastewaters. The biological reactor consists of a vertical shaft partitioned into a downflow section (downcomer) and an upflow section (riser) and surmounted by a gas disengagement tank. The bioreactor diameter depends on the flow and strength of the wastewater and can be as small as 40 cm (16 in.).

Wastewater enters the system continuously and, together with return activated sludge, is circulated within the bioreactor. Mixed liquor is discharged from the shaft under a slight pressure for solids separation. Circulation of liquid is initially induced by injecting compressed air at a relatively shallow depth (30 to 60 m (100 to 200 ft) below the surface) in the riser section. Part of the air flow is then gradually transferred from the riser to a second injection point situated in the downcomer section 30 to 60 m (100 to 200 ft) below the surface. Air entering the downcomer is forced to travel downward through the downcomer and then up the riser section before release. The greater density of downcomer liquid above the point of air injection in the downcomer section produces a net driving force for circulation.

Many potential advantages have been claimed in the literature for the Deep Shaft process over conventional activated sludge systems including (12)(17)(21)

1. less land area requirements,
2. less energy consumption,
3. less sludge production,
4. lower capital and operating costs, and
5. elimination of primary settling.

The potential economic savings are attributed to substantially higher organic loading capacity, reduced reactor detention time, more efficient oxygen and power utilization through improved contacting, reduced sludge processing requirements, and the production of a thicker waste activated sludge that is easily dewatered without chemical addition.

U.S. Environmental Protection Agency (U.S.EPA) scientists were aware of the Deep Shaft pilot studies taking place in the United Kingdom, Europe, and Canada from 1975 to 1978. To investigate the potential application of Deep Shaft technology in the United States, an Agency decision was made to sponsor an evaluation project. After preliminary discussions with several municipalities, the City of Ithaca, New York, was selected as an acceptable site to locate a pilot plant to demonstrate the feasibility of the Deep Shaft process and to evaluate its application for the treatment of municipal wastewater. Effective September 21, 1978, a U.S.EPA cooperative demonstration agreement (No. CS806801) was entered into with the City of Ithaca to construct and operate a 757-m^3/day (0.2-mgd) Deep Shaft pilot demonstration plant at the City's existing wastewater treatment plant site.

Specific project objectives as set forth in the grant application documents were to

1. evaluate the efficiency and reliability of the Deep Shaft process in treating a typical municipal wastewater in the United States under various operating conditions,
2. provide quidance to engineers in the United States on the applicability of the Deep Shaft process to municipal treatment practices and to define critical design and operating parameters,
3. compare solids separation performance and associated operating characteristics in both the flotation and gravity clarification modes,
4. develop capital and operating cost estimates to apply Deep Shaft technology to a wide range of municipal projects,
5. define flotation chemical aid requirements, if any,
6. compare Deep Shaft operation and performance (including sludge production and energy consumption) to traditionally accepted operating and performance values for conventional activated sludge systems, both air and oxygen,
7. evaluate process performance and phosphorus removal with and without alum addition,
8. compare process performance on raw wastewater feed versus primary effluent feed, and
9. determine whether typical U.S. municipal treatment plant personnel could be trained to effectively, routinely, and independently operate a Deep Shaft system.

SECTION 2

CONCLUSIONS

1. The Deep Shaft process is a high-rate, high-intensity activated sludge process utilizing flotation for solids separation. At Ithaca, food-to-microorganism (F/M) loadings were in the range of 0.5 to 1.0 kg BOD_5/day/kg MLVSS; solids retention times (SRT) were 1 to 4 days; and bioreactor hydraulic retention times (HRT) were 45 to 53 min, exclusive of recycle flows.

2. Numerous problems including operator control, mechanical breakdowns, partial shaft blockages caused by partial grinding and subsequent return of screenings to the influent flow at the main plant headworks, foaming conditions, and abnormally strong digester returns adversely affected process performance and often resulted in the collection of inconclusive and inconsistent data. There were only a few periods in the first 50 wk of operation when problems were not encountered and a routine operation could be established. By the last 14 wk of operation, most major problems had been overcome. Prior to flushing the secondary riser portion of the shaft, the system was prone to upset caused by partial shaft blockages and excessive foaming resulting in several shaft stalls and overflows. These situations would probably not occur at full-scale Deep Shaft applications utilizing larger diameter shafts where shaft internal channels would be larger and where either screenings removal or more thorough screenings grinding than that available at Ithaca would be employed.

3. A number of physical changes were made to the system during the 64-wk operating period. These included elimination of the swirl tank plug valve and automatic head tank level controls by addition of a gravity recirculation line and control valve from the flotation tank to the holding tank, separation of the two riser air lines, modification of the oxidation tank return line, and the installation of additional bar racks in the Deep Shaft influent channel.

4. For those time periods focused on for process evaluation when a routine operation on raw wastewater was established, effluent concentrations of BOD_5 and suspended solids averaged 20 and 27 mg/l, respectively, and percent removals

were 80 and 88 percent, respectively. These percent removals are for the Deep Shaft process only and do not account for any reductions that may have occurred in the main plant degritting operations. Effluent soluble BOD_5 concentrations were consistently below 10 mg/l during all phases and modes of operation, even when operational problems or adverse conditions were encountered. Nitrification inhibitors were not utilized in the BOD_5 analysis, although some nitrification occurred near the end of the study.

5. The process was more effective in treating raw wastewater than in treating primary effluent, perhaps because of the latter's more dilute nature (lower organic loading) and lack of fibrous material.

6. The system did not operate as well under diurnal flow variations as under constant flow conditions. The peak hydraulic capacity of the system was such that wet-weather peak flow conditions typical of Ithaca could not be simulated. The effects of flow peaking factors greater than 1.4 times design average flow could not be evaluated.

7. Polymer addition did increase the quantity of the float blanket but did not appear to significantly improve effluent quality. Low polymer dosages adversely affected solids separation by causing some sink solids to remain suspended. At full-scale Deep Shaft plants, polymer addition facilities may be desirable for use on an intermittent or seasonal basis as necessary.

8. Alum addition for phosphorus removal while treating primary effluent appeared to adversely affect the float blanket by causing solids to sink. In full-scale applications, the need for tertiary treatment of the Deep Shaft effluent to obtain phosphorus removal will depend on the yet-to-be-determined compatibility of in-process alum or iron addition with Deep Shaft operations when the system feed is degritted raw wastewater rather than primary effluent. Tertiary facilities, if needed, could add significantly to the capital and operating costs of the system compared to conventional activated sludge systems.

9. Limited data collected during cold weather operation were inconclusive as severe foaming and partial shaft blockages were encountered at the same time.

10. The Deep Shaft process handled shock organic loadings from solids processing returns very well and recovered within 12 to 24 hr after cessation.

11. The float blanket and solids separation unit appeared to be more susceptible to upset from operational problems and adverse conditions than the biological oxidation process.

12. Waste sludge production measurements were complicated by a large contribution of digested and partially digested anaerobic solids received at the pilot plant. Waste sludge production calculations based on primary effluent feed indicated that the sludge production rate was similar to that reported for conventional activated sludge systems.

13. A large quantity of solids would not float and sank to the bottom of the flotation tank. During some periods, sink wasting requirements exceeded float wasting requirements. Waste float solids concentrations ranged from 1.6 to 4.8 percent, and waste sink solids concentrations were around 2 percent. Polymer addition increased the quantity of float solids but not the concentration.

14. Unless required for other reasons, the use of primary settling tanks is not necessary or economically advantageous with the Deep Shaft process. No savings in Deep Shaft energy requirements will be realized from the reduction in BOD_5 concentration associated with primary treatment unless the wastewater has a high organic strength. The need for primary settling should be determined by other factors such as types of recycle streams back to the head of the plant or the need to handle "first-flush" solids from combined sewer systems.

15. Ithaca's Deep Shaft system required significant operator training, attention, and control. Control of the solids inventory and maintenance of a good, thick float blanket required much operator judgment in wasting float solids, wasting sink solids, and determining the sink recycle rate on a day-to-day basis. Operation of the pilot plant was made substantially more difficult due to problems at the main plant including inadequate grinding of screenings, plant bypassing, and digester operations.

16. Gravity clarification can be achieved with degassing of Deep Shaft mixed liquor, but this mode of operation eliminates many inherent advantages of the process and probably would not be economically competitive with conventional systems. Gravity clarification was omitted from the experimental program as the results would have been of academic interest only.

17. The Deep Shaft process underwent further development by Eco Technology during the course of the evaluation period, culminating in an Eco III design that represents the current

state-of-the-art in Deep Shaft technology. With limited full-scale operating experience available to date, no attempt is made herein to predict the improvement in process operation and performance that could be expected with an Eco III design compared to that observed with the modified Eco II design at Ithaca.

SECTION 3

DESCRIPTION OF DEEP SHAFT PROCESS

BACKGROUND

The Deep Shaft process was developed by Imperial Chemical Industries Ltd. (ICI) in the United Kingdom and Europe (6)(21). It originated from basic aerobic fermentation technology developed by the Agricultural Division of ICI for the production of single-cell protein from methanol. Single-cell fermentation utilizes a substrate that is easily metabolized; the resulting organism growth rates are very high. High-rate biological kinetics require extremely high oxygen transfer intensities to maximize cell production. Therefore, to achieve these transfer intensities and to minimize operating costs, the air-lift type fermenter was developed. This type of technology utilizes a pressure cycle contactor in which air for biological oxidation also provides the driving force for liquid circulation by producing different voidages of gas in various sections of the reactor. Oxygen transfer intensities of 10 kg $O_2/m^3/hr$ (0.62 $lb/ft^3/hr$) resulting in an oxygen transfer efficiency of 50 percent and an aeration efficiency of 1.5 kg O_2/kWh (2.5 lb/wire hp-hr) have been reported (6)(21).

Treatment of municipal wastewaters, which normally have lower microorganism concentrations, less biodegradable substrates, and slower microorganism growth rates, does not require as high an oxygen transfer intensity. Another significant difference between wastewater and fermentation applications is the goal of minimizing rather than maximizing cell production (21). For these reasons, it was necessary to modify the air-lift fermenter to provide a much longer bubble contact time for wastewater treatment by increasing the length of the reactor to achieve higher oxygen transfer efficiency and power economy. This modification resulted in the development of the Deep Shaft process.

The first Deep Shaft pilot facility was constructed in 1974 at the Billingham Sewage Treatment Works in Great Britain. The objectives of the ICI pilot plant study (21) were to

1. prove that modified fermentation technology can be applied to the treatment of domestic wastewater,

2. determine resulting sludge characteristics and how well sludge would separate from the treated wastewater, and
3. determine sludge production rates.

Initially, the solids separation sequence included both flotation and mechanical degassing followed by sedimentation. Solids separation by means of flotation utilized fine bubbles already present in the rising liquid. Flotation provided a thickened float to permit rapid return of sludge to the reactor or for subsequent dewatering. Degassing was provided to eliminate the interference of residual air bubbles when sedimentation was employed for solids separation.

The solids separation sequence at the Billingham pilot facility was modified in September 1975 to improve effluent quality and simplify operation. The flotation tank was eliminated, and mechanical degassing was substituted with a vacuum degasser prior to the sedimentation tank. The pilot unit was evaluated in the gravity clarification mode at constant and variable flows for almost a year (17).

PROCESS DESCRIPTION

The Deep Shaft biological treatment process is essentially a high-rate activated sludge process capable of operating at F/M loadings between 0.5 and 2.0 kg BOD_5/day/kg MLVSS (25). In addition, high volumetric loadings are achievable because of the capability of the system to carry and maintain mixed liquor volatile suspended solids (MLVSS) concentrations between 5,000 and 10,000 mg/l (26). As a result, a much lower bioreactor volume (aeration period) is required than in the conventional activated sludge process.

Deep shafts are self-contained vertical subsurface aeration reactors normally between 90 and 250 m (300 and 800 ft) deep with mean HRT's of approximately 40 to 60 min for municipal-strength wastewater (5)(12)(15). The HRT generally increases with increasing wastewater strength. The reactor is divided into two sections, namely, a downcomer and a riser. A simplified schematic of the basic ICI Deep Shaft reactor is shown in Figure 1.

Raw wastewater, after screening and degritting, and return sludge continuously enter the downcomer section of the shaft and flow downward. From the downcomer, aerated liquid passes into the riser section and flows upward. A portion of the mixed liquor overflows the shaft to a solids separation process, and the remainder of the mixed liquor is recirculated to the downcomer. Mixed liquor is circulated many times within the shaft during its residence in the reactor.

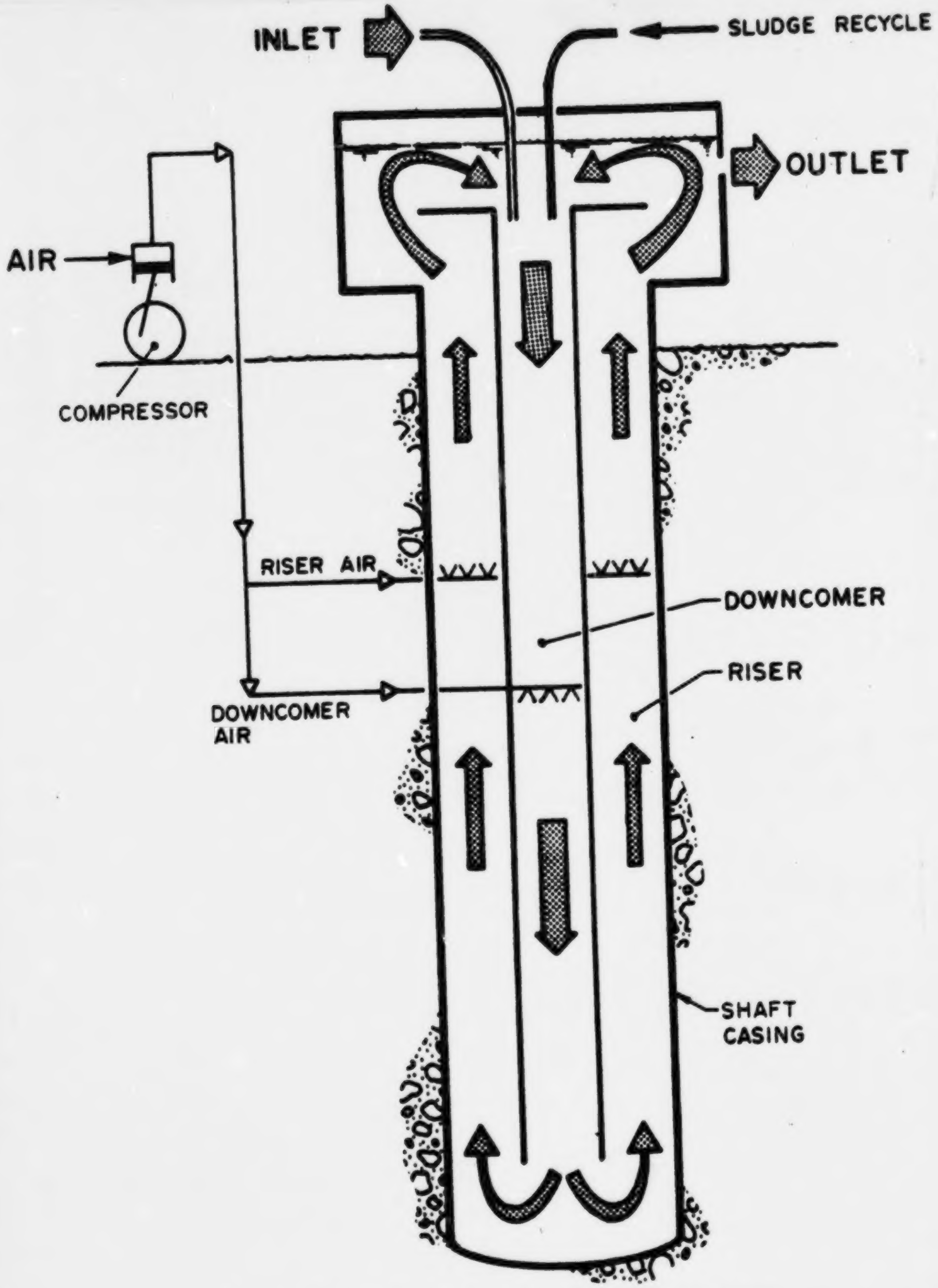


Figure I. ICI shaft configuration and hydraulics (16).

Compressed air is piped into the Deep Shaft to provide the oxygen required for treatment as well as the driving mechanism to maintain circulation velocities between 0.9 and 1.5 m/sec (3 and 5 ft/sec) (6). Initially, compressed air is injected into the riser section at a depth of approximately 30 to 60 m (100 to 200 ft) below the top of the shaft. The air displaces a portion of the liquid in the riser section. This volume of air or gas voidage in the riser section results in a gas/liquid dispersion with less net density than the liquid in the downcomer section. In effect, the liquid in the downcomer is heavier and, therefore, a pressure differential exists between the downcomer and riser sections. The higher pressure on the downcomer side pushes up the liquid in the riser, causing the liquid to flow upward. Liquid is pushed out of the top of the riser into a basin called the head tank that is surmounted on top of the shaft. The head tank is adequately sized to allow gas disengagement from the liquid before returning to the downcomer. Gas disengagement is required so that a net difference in gas voidage between the downcomer and riser can be maintained.

Once stable circulation is obtained, the large difference in voidage between the downcomer and riser is not required. Only a small pressure difference is necessary to keep the mixed liquor circulating. Therefore, to minimize anoxic areas within the shaft, a portion of the air is transferred from the riser section to the downcomer section. Since the velocity of the liquid in the shaft is approximately three to five times greater than the bubble rise velocity, air injected into the downcomer is drawn down the shaft by the liquid flow. As the air and mixed liquor flow further down the shaft, the pressure due to hydrostatic head on liquid depth increases. Since the solubility of gas is proportional to the pressure, at greater depths more air is dissolved and the voidage decreases. Most of the gas bubbles are dissolved at the bottom of the shaft. As the mixed liquor travels up the riser section of the shaft, the hydrostatic pressure decreases and gas bubbles form containing carbon dioxide, nitrogen, and unused oxygen.

The shaft's great depth together with the long path that the air bubbles take and the intense turbulence give the Deep Shaft its ability to transfer oxygen very efficiently and at extremely high rates. These high rates, in turn, are only achievable because the system makes it possible to inject large quantities of air into the circulating liquid without exceeding voidage constraints above which bubble coalescence becomes substantial (21).

DEVELOPMENT BY C-I-L INC. IN CANADA

In 1975, ICI in the United Kingdom extended process licenses to its Canadian affiliate C-I-L Inc. Eco Technology, a wholly-owned subsidiary of C-I-L Inc., was responsible for the development of the Deep Shaft process in North America.

Optimization of the ICI Deep Shaft Flowsheet

Eco Technology established a pilot plant in Paris, Ontario, Canada, to optimize the ICI Deep Shaft flowsheet. Flotation rather than sedimentation was used for solids separation to eliminate the degassing step necessary to strip residual air bubbles from the mixed liquor exiting the shaft when employing gravity clarification. The rationale for this selection, in part, was avoiding the capital and operation and maintenance costs associated with the additional step. In addition, Deep Shaft aeration followed by flotation clarification offered the potential to significantly reduce bioreactor volume and to make multiple use of compressed air for biological treatment, circulation of mixed liquor through the shaft, and flotation separation. Flotation allowed the bioreactor to be operated at mixed liquor suspensed solids (MLSS) concentrations in excess of 10,000 mg/l without adversely impacting suspended solids separation. Flotation clarification can yield a solids float concentration in excess of 5 percent, which reduces the return sludge volume and can eliminate the need for additional thickening prior to dewatering.

The pilot plant constructed at Paris utilized the basic shaft configuration developed by ICI and is referred to as Eco I. In this configuration, influent wastewater and return sludge are added to the head tank at the top of the shaft. Mixed liquor is drawn off from the side of the head tank for subsequent clarification.

The pilot plant studies at Paris, Ontario, were conducted at a flow of 454 m^3/day (120,000 gpd) of combined domestic and industrial wastewater (6). Average values for influent BOD_5 and suspended solids were 141 and 217 mg/l, respectively. Ten mg/l of liquid ferric chloride was added to the raw wastewater at Paris for phosphorus removal. The shaft at Paris had an inside diameter of 39 cm (15.25 in.) and a depth of 155 m (508 ft), providing a nominal detention time of 55 min. With an average MLSS concentration of 6,000 mg/l, the F/M loading averaged 1.0 kg BOD_5/day/kg MLVSS. A flotation area of 13.9 m^2 (150 ft^2) was provided. Because of the high surfactant load of 30 mg/l average and 150 mg/l peak from the industrial wastes, 10 mg/l of polymer was required to stabilize flotation clarification (6). Diurnal flow variations were not employed.

Effluent quality for the period of March-June 1977 averaged 24 mg/l for BOD_5, 15 mg/l for soluble BOD_5, and 29 mg/l for suspended solids. Weekend operating results with a lower industrial load were better with average effluent BOD_5 and suspended solids values of 13 and 18 mg/l, respectively (6).

Short-term operating results (1 mo) at a flow of 681 m^3/day (180,000 gpd) and a nominal shaft detention time of 35 min produced effluent quality values of 23 mg/l for BOD_5 and 28 mg/l for suspended solids. For a 2-wk period, the textile mill and associated surfactant contributions were eliminated. Under these conditions, stable operation was achieved with a polymer dose of 3 mg/l (6).

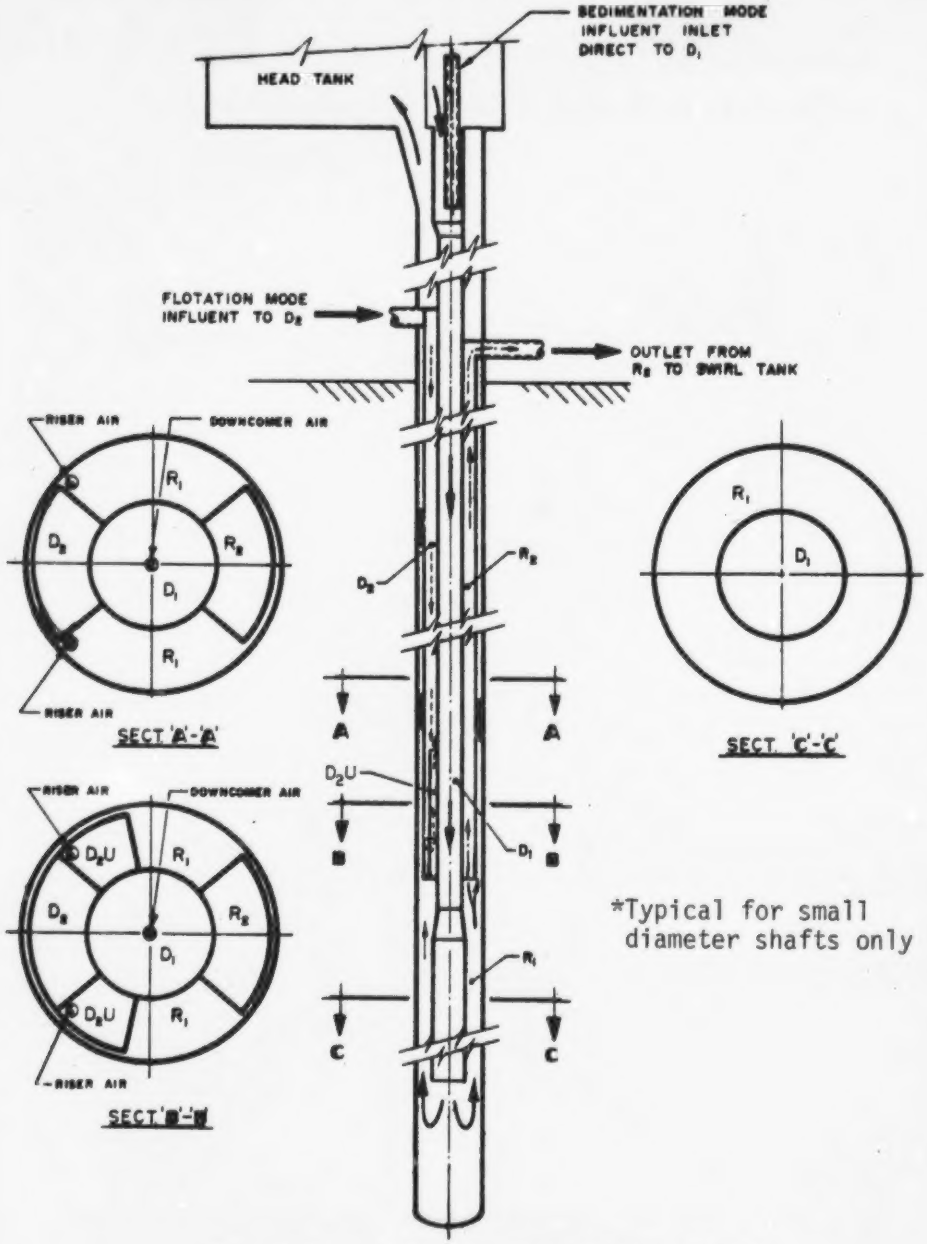
Development efforts through the late 1970's were directed at eliminating the need for chemical flotation aids and improving operational stability of flotation clarification.

Shaft Modifications (6)

Once the feasibility of employing flotation for clarification became evident, Eco turned its attention to modifying the design and operation of the shaft to enhance its compatibility with flotation separation. Examination of Figure 1 reveals that the upper section of the shaft downcomer is not aerated, except for residual dissolved oxygen (DO) carrying over from the riser. The combined mixture of influent wastewater and return sludge introduced at the top of the downcomer in the ICI and Eco I configurations does not contact a fresh supply of DO until it reaches the downcomer air injection point at approximately the 40-percent depth level of the shaft. Consequently, as much as 15 to 20 percent of the total shaft circulation route may be anoxic, depending on wastewater strength and the MLSS concentration. It is apparent that the upper section of the downcomer leg is not the most effective section of the shaft for satisfying the high initial oxygen demand of the substrate.

A feature of the ICI and Eco I shaft operating modes that is counterproductive to efficient flotation is the withdrawal of mixed liquor at the surface. As mixed liquor travels up the riser leg, it degasses. By the time it reaches the head tank, much of the carbon dioxide, nitrogen, and unused oxygen, which were dissolved in the lower section of the shaft, has been stripped from solution. The dissolved gas driving force for inducing flotation clarification of mixed liquor solids is thereby considerably reduced.

Improvements in the operation and geometry of the Eco I shaft to minimize anoxic zones and to maximize the driving force for inducing flotation clarification led to the development of a revised shaft configuration, Eco II. As illustrated in Figure 2, Eco II utilizes a multi-channel design concept featuring one primary downcomer (D_1), one primary riser (R_1), one secondary downcomer (D_2), and three secondary risers (one designated R_2 and two designated D_2U). The secondary downcomer and secondary risers are restricted to the upper 35-50 percent of the shaft. The primary downcomer and primary riser run the full depth of the shaft. In the lower section of the shaft, the primary riser



*Typical for small diameter shafts only

Figure 2. Eco-II shaft configuration and hydraulics (16).*

occupies the full annulus between the primary downcomer and the outer casing. In the upper section in the area of the secondary downcomer and secondary risers, the primary riser consists of two channels occupying only a portion of the annulus.

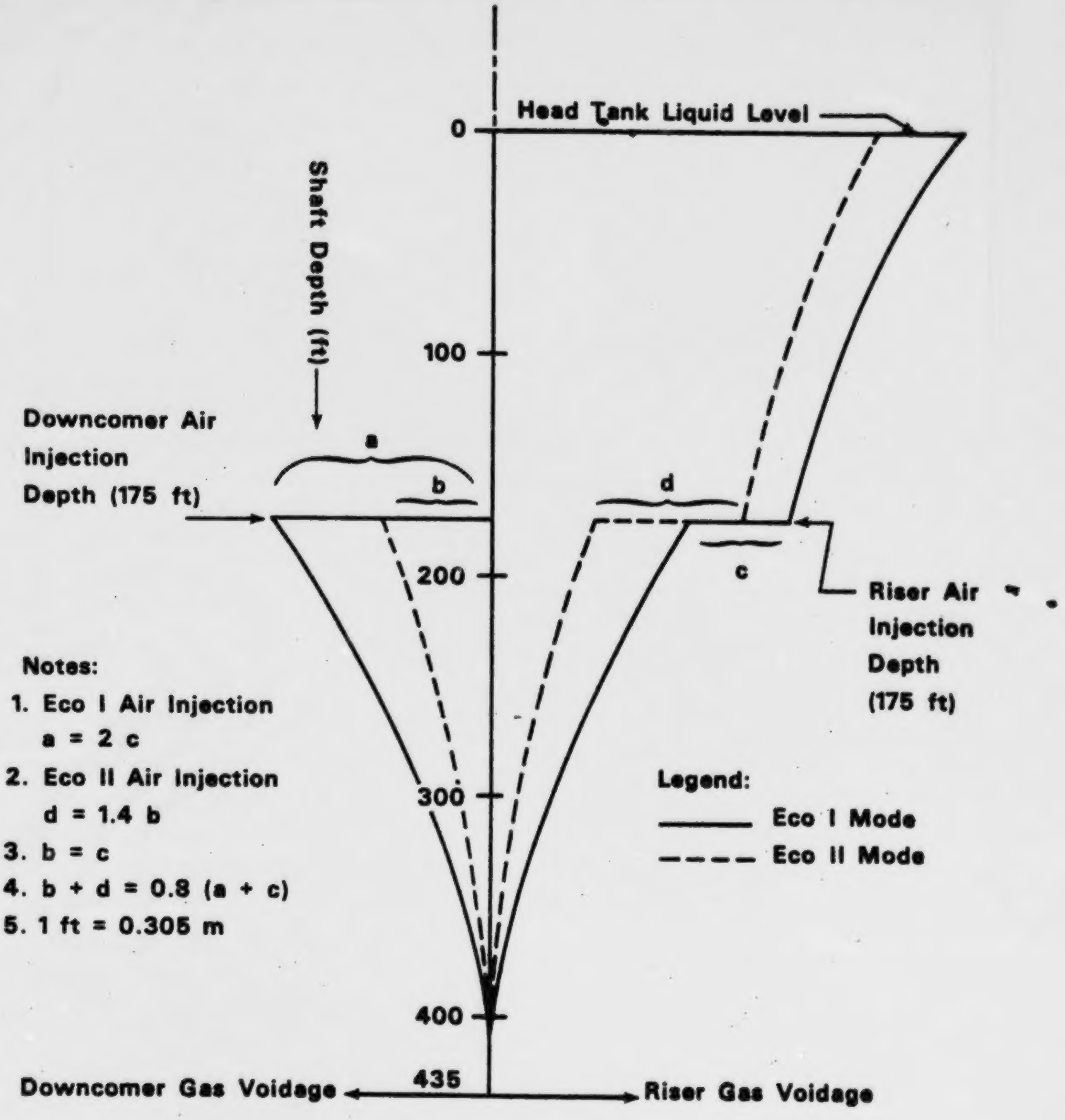
Influent wastewater and return sludge are introduced to the shaft through the D_2 secondary downcomer. The D_2 downcomer is turned up at its lowest point, forcing the influent-return sludge mixture back up the two short D_2U secondary risers and into the two upper R_1 primary riser channels. The injection level where the D_2U sections discharge into the upper primary riser channels is normally selected to fall within the range of one-quarter to one-half the shaft depth.

Compressed air is injected into the upturned D_2U risers near the bottom. Influent wastewater and microorganisms are thereby contacted with makeup air at a point of high oxygen solubility. The two upper channels of the primary riser now become the zones of initial high oxygen uptake, rather than the upper downcomer section as in the ICI and Eco I shaft designs.

Air injection into the D_2U secondary risers serves two purposes. First, it aspirates the influent wastewater-return sludge mixture into the shaft at depth using the air-lift principle. Second, it provides the motive force (along with primary downcomer air) for circulating mixed liquor around the shaft's main primary downcomer-primary riser loop at a rate about eight times greater than the influent wastewater flow rate. Thus, influent wastewater is diluted on entering the shaft at an approximate ratio of 8:1. The resulting fluid velocities and detention times per pass are on the order of 0.9 to 1.5 m/sec (3 to 5 ft/sec) and 4 to 6 min, respectively.

The second major design change in the Eco II shaft is the relocation of the mixed liquor withdrawal point from the head tank to the R_2 secondary riser. R_2 runs within the R_1 primary riser from the withdrawal point to the surface. The entrance to R_2 is located slightly below the point at which influent wastewater and return sludge are injected into R_1. This arrangement precludes the possibility of short-circuiting untreated wastewater directly to the shaft effluent line. The two principal advantages of the revised method of transporting liquid from the shaft are the transfer of mixed liquor to the flotation tank with a higher dissolved gas content and the provision of maximum treatment time per pass following the initial contact of incoming substrate, biomass, and injected air.

Typical Eco I and Eco II gas voidage diagrams are presented in Figure 3 for a 133-m (435-ft) deep shaft with an assumed air injection depth in both legs of 53 m (175 ft). Gas voidage is defined as the volume of undissolved gas per unit volume of



Notes:

1. Eco I Air Injection
   a = 2 c
2. Eco II Air Injection
   d = 1.4 b
3. b = c
4. b + d = 0.8 (a + c)
5. 1 ft = 0.305 m

Figure 3. Typical Eco I and Eco II gas voidage diagrams (6).

liquid. The shape of the voidage diagrams is directly related to the amount and distribution of air injected. In the Eco I design, approximately two-thirds of the total air supply is added to the downcomer and one-third to the riser. Conversely, the Eco II design adds only one-third to one-half of the total air supply to the primary downcomer and one-half to two-thirds to the primary riser through the D2U sections. More air is needed proportionally in the riser of an Eco II shaft due to the aforementioned introduction of wastewater and return sludge in the upper section of this leg. Another distinction is that total air requirements to sustain circulation at desired velocities are about 20 percent less for Eco II than Eco I and will result in power savings for low strength wastewaters.

The shift in air injection toward the downcomer leg once circulation is established is greater in the Eco I than in the Eco II operating mode. The retention of a higher percentage gas voidage in the upper riser sections of an Eco II shaft results in improved hydraulic stability and significantly reduces the potential for hydraulic reversal to occur.

The claims made for the Eco II bioreactor can be summarized as follows:

1. Anoxic zones within the shaft are virtually eliminated.
2. Substrate removal kinetics and the shaft's overall biological profile are enhanced owing to the better matching of oxygen demand with oxygen availability.
3. Single-pass plug flow treatment time in a high-intensity aerobic environment is maximized.
4. Total air requirements are decreased and organic loading capacity is increased by 15 to 20 percent each.
5. Dissolved gas phenomena for suspended solids separation by flotation is optimized.
6. The overall improvement effected in flotation performance (item 5) reduces or eliminates the need for the addition of polymers or other flotation aids to achieve a high degree of suspended solids removal in the final effluent.
7. Hydraulic stability of the circulating mixed liquor is improved.

ECO II SYSTEM DESCRIPTION (6)

The complete Eco II system, shown schematically in Figure 4, is comprised of more than a bioreactor and a flotation clarifier. Auxiliary tanks and piping are an integral part of the system design. For simplicity, the shaft has been depicted as a single tube with a divider wall forming the primary downcomer and primary riser legs. The D_2 secondary downcomer and the R_2 secondary riser are shown, but the short D_2U secondary riser sections have been omitted for clarity.

In contrast to an Eco I head tank, which is enclosed but supplied with a direct vent to the atmosphere, an Eco II head tank is enclosed and pressurized. Oxygen losses from the head tank are thereby minimized, allowing higher concentrations of DO to be carried over to the downcomer than would remain in equilibrium with the atmosphere. Disengaged bubbles exit the head tank as off gas to a foam oxidation tank. The foam oxidation tank is vented.

Partially treated or collapsed foam is displaced to the holding tank and eventually back into the shaft. Raw influent and floated return sludge also enter the shaft from the holding tank after first being contacted and mixed in a trough that runs along and slightly below the flotation tank beach. Bottom return sludge is recycled to the holding tank in a separate line. The mixture of influent wastewater, float return sludge, bottom return sludge, and collapsed foam is air lifted into the shaft via the secondary downcomer (D_2) and secondary risers (D_2U), as illustrated previously in Figure 2.

The swirl tank briefly intercepts mixed liquor as it is transported to the flotation tank. The residence time in the swirl tank is long enough to strip out large bubbles that would disrupt flotation, but not so long to promote effervesence of dissolved gases and/or small bubbles.

The pressure required to force the mixed liquor out through the R_2 secondary riser is provided by the difference between the liquid levels in the head tank and the swirl tank (distance A in Figure 4) plus the depth of submergence of the foam transfer line (distance B in Figure 4). This head differential offsets the friction losses in the R_2 section. Therefore, as the liquid level in the head tank increases, the output of R_2 increases. To limit the height requirements of the head tank, it is pressurized to between 2,100 and 5,600 kgf/m^2 (3 and 8 psig). This is equivalent to increasing the liquid level in the head tank. The exact pressure in the head tank is governed by the

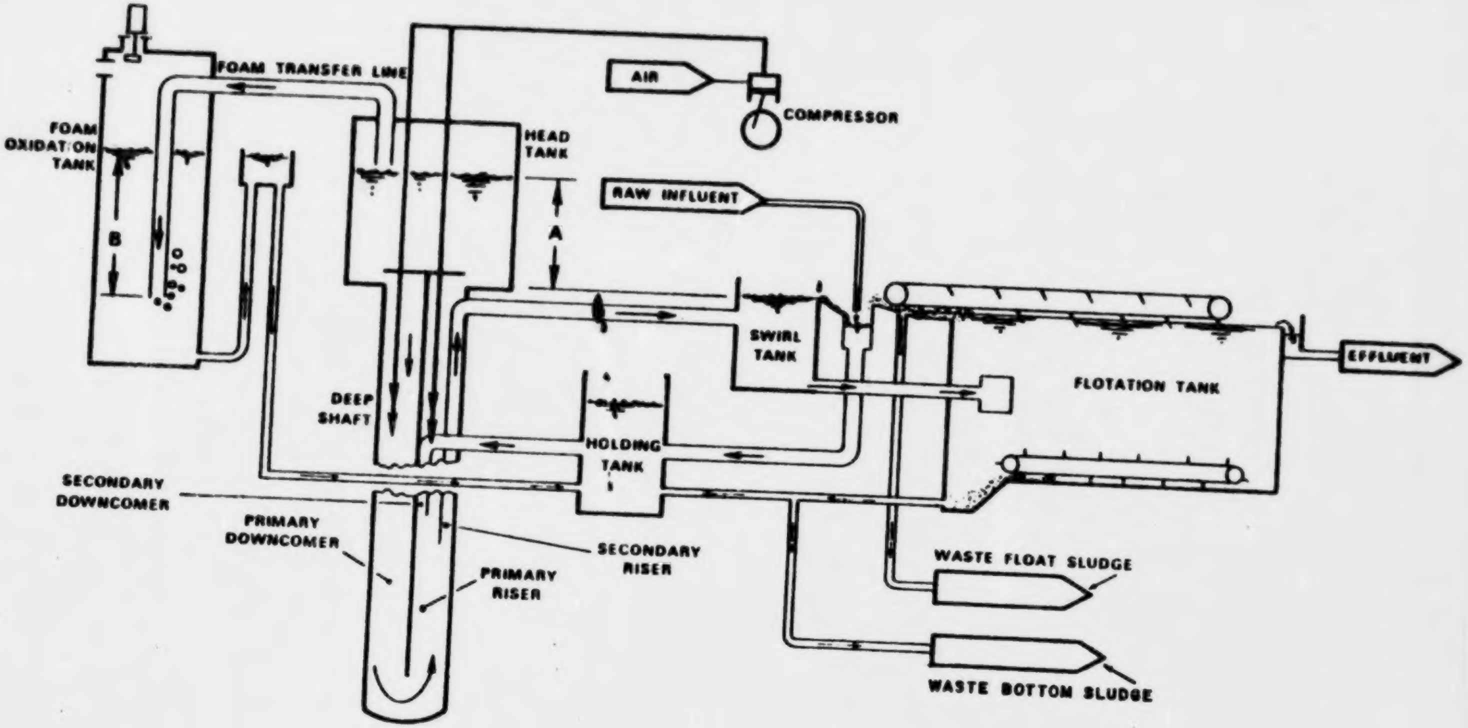


Figure 4. Schematic of Deep Shaft system using flotation clarification (6).

liquid level in the foam oxidation tank (distance B in Figure 4). The height of liquid above the bottom of the air outlet pipe in the foam oxidation tank is proportional to the pressure in the head tank.

If polymer or other chemicals are required to aid in flotation separation, they are introduced to the mixed liquor in the pipe directly beneath the swirl tank feeding the flotation tank. Variable rate skimmers are provided to collect the floated solids and draw them toward and onto the beach. Mixed liquor solids not amenable to flotation will sink. These solids are collected by bottom scrapers and a screw conveyor for direct gravity return to the holding tank, as shown in Figure 4, or for pumped return to the influent trough fronting the beach.

Wasting of floated solids is accomplished through an orifice in the beach. An automatically timed valve in the waste sludge line is used to control the float solids wasting rate. Bottom solids wasting is controlled manually by a valve located in the discharge line of the pump used to return sink solids to the influent trough.

FLOTATION DESIGN AND OPERATIONAL IMPROVEMENTS

Based on the experience gained with the operation of both Eco I and Eco II systems, a third generation system configuration was developed by Eco Technology, hereinafter referred to as Eco III. The second generation Deep Shaft reactor configuration (Eco II) optimized the biological profile inside the reactor and stabilized the hydraulic flow pattern. The air supply requirements for the Eco II reactor, however, were determined predominantly to maintain liquid circulation at peak flow conditions. One of the improvements in the Eco III reactor design involves the more efficient use of the aeration energy by controlling the air flow rate to match influent wastewater flow (25).

The Eco III model has the same multichannel configuration as Eco II. The major improvements in the Eco III design involve the elimination of the swirl tank and extensive process control instrumentation and design improvements in the flotation unit. The following claims were made as a result of these design changes (25):

1. Lower effluent suspended solids are produced, and flotation reliability and operating costs are improved.

2. Mechanical flow controls and pumps are eliminated through the effective use of gravity recycle of sink solids and hydraulic controls.

3. Dissolved air flotation performance is enhanced by eliminating the swirl tank and modifying flotation tank internals.

4. The number of operator controlled variables is reduced by improving the ease of operation of the system.

5. Hydraulic performance of the systemois improved over a wide range of diurnal and storm flow variations.

The Eco III design resulted in a more space efficient treatment system. In addition, the redesign of the head and foam tanks provided the hydraulic control to allow the flotation system to operate over a wider range of influent flow conditions.

In the Eco III design, the bottom solids recycle to the shaft is controlled hydraulically by a conduit connected to the holding tank, which is the collection point for influent and recycle streams entering the shaft. During periods of high influent flow, the back pressure against the flow from the bottom solids recycle conduit increases reducing this flow and resulting in a constant flow to the flotation tank. During periods of low influent flow, the head resistance to the bottom solids recycle is reduced allowing this flow to increase to maintain a constant flow to the flotation tank from the shaft. In general, any deviations in the influent flow rate will be balanced with variations in return sink flow rate from the flotation unit. The gravity return of settled sink sludge from the flotation unit to the holding tank allows automatic control of the sink sludge flow in proportion to the hydraulic head difference between the flotation unit and the holding tank. As a result, the Eco III Deep Shaft reactor and flotation unit operate under constant hydraulic and solids loadings, respectively.

The other design modification in the Eco III reactor system involves the flotation separator unit (25). The flotation separator for the Eco III reactor system is equipped with a 'J' baffle and a specially designed float sludge skimming ramp. The 'J'-shaped baffle serves as an impinging barrier for the mixed liquor feed and helps to separate and release the coarse air bubbles from the feed stream. These coarse air bubbles are vented through spitter tubes with discharge into the influent trough. As a result, the swirl tank requirement has been eliminated and the mixed liquor from the Deep Shaft reactor can be directly fed to the flotation separator. Similarly, the float sludge skimming ramp serves to circulate the mixed liquor feed stream around the 'J' baffle and is believed to promote flocculation of the mixed liquor suspended solids.

The above shaft and flotation tank design represents the state-of-the-art of Deep Shaft technology. This design is claimed to provide improved operational stability, simple construction, and improved flotation.

SECTION 4

DESCRIPTION OF FACILITIES

EXISTING WASTEWATER TREATMENT FACILITIES

The City of Ithaca is located in New York State at the south end of Cayuga Lake approximately 80 km (50 mi) southwest of Syracuse. The City's climate ranges from severe freezing in the winter to high temperatures in the summer. Ithaca is the home of Cornell University and Ithaca College, which contribute substantially to the City's waste load.

Ithaca's existing wastewater treatment plant provides primary clarification and secondary treatment using the trickling filter process for a population equivalent of 40,000. The primary treatment section of the plant and trickling filter units were constructed in 1961. The secondary settling tanks and sludge digestion facilities date back to 1938. These facilities have an average design flow rate of 15,100 m^3/day (4 mgd) with peak flow capacity to 60,600 m^3/day (16 mgd). Currently, the average dry weather flow is approaching 26,500 m^3/day (7 mgd). Peak flows in excess of 60,600 m^3/day (16 mgd) occur occasionally throughout the year. The City's wastewater is primarily domestic with sufficient flow to permit a sidestream demonstration study of the Deep Shaft process without disrupting main plant operations. In addition, a diversity of waste streams was available to the pilot plant, including raw wastewater and primary and trickling filter effluents plus anaerobic digester supernatant and vacuum filter filtrate.

Major facilities of the City of Ithaca's existing wastewater treatment plant include

1. one mechanically-cleaned and a standby manually-cleaned bar screen with screenings grinder,
2. raw wastewater pumping and flow measuring facilities,
3. aerated grit chamber,
4. two primary settling tanks,
5. two trickling filters with recirculation pumping facilities,

6. two final settling tanks,
7. chlorination facilities,
8. anaerobic sludge digestion facilities, and
9. vacuum filtration facilities.

The relationship of the Deep Shaft pilot demonstration plant to the Ithaca main plant treatment facilities is illustrated schematically in Figure 5. A sidestream of raw wastewater after screening and grit removal or primary effluent was diverted to the Deep Shaft pilot facilities. No piping was provided to introduce trickling filter effluent to the Deep Shaft plant. An evaluation using trickling filter effluent as feed would have been of interest only in evaluating nitrification. Digester supernatant and vacuum filter filtrate are returned to the plant influent. Treated effluent and waste sludge from the demonstration plant were pumped to the influent end of the main plant primary clarifiers to preclude any discharge of pilot effluent streams to the receiving water. To facilitate winter operation and protect the solids separation unit during flotation operations, a 20.7-m by 10.7-m (68-ft by 35-ft) metal building was constructed to house the entire Deep Shaft demonstration facilities.

DESIGN AND CONSTRUCTION OF PILOT PLANT FACILITIES

The Ithaca pilot demonstration system was flexibly designed to permit operation in two different modes. These two modes were flotation clarification utilizing the Eco II design and gravity clarification preceded by vacuum degassing utilizing the original ICI design. The shaft was constructed to operate with secondary downcomer and riser sections (Eco II) or without them (ICI). A single liquid-solids separation tank was provided to serve as both a flotation clarifier and a gravity clarifier.

Ithaca's Deep Shaft demonstration plant was designed to have a nominal capacity in the flotation clarification mode (Eco II flowsheet) of 757 m^3/day (200,000 gpd) at an influent BOD_5 concentration of 150 mg/l. Due to solids loading constraints and corresponding lower attainable MLSS concentrations, nominal design capacity in the gravity clarification mode (ICI flowsheet) was only 379 m^3/day (100,000 gpd). Diurnal flow variation capability was provided to simulate typical flow patterns observed at municipal wastewater treatment plants. Design criteria and operating parameters for the Ithaca Deep Shaft pilot plant are summarized in Table 1.

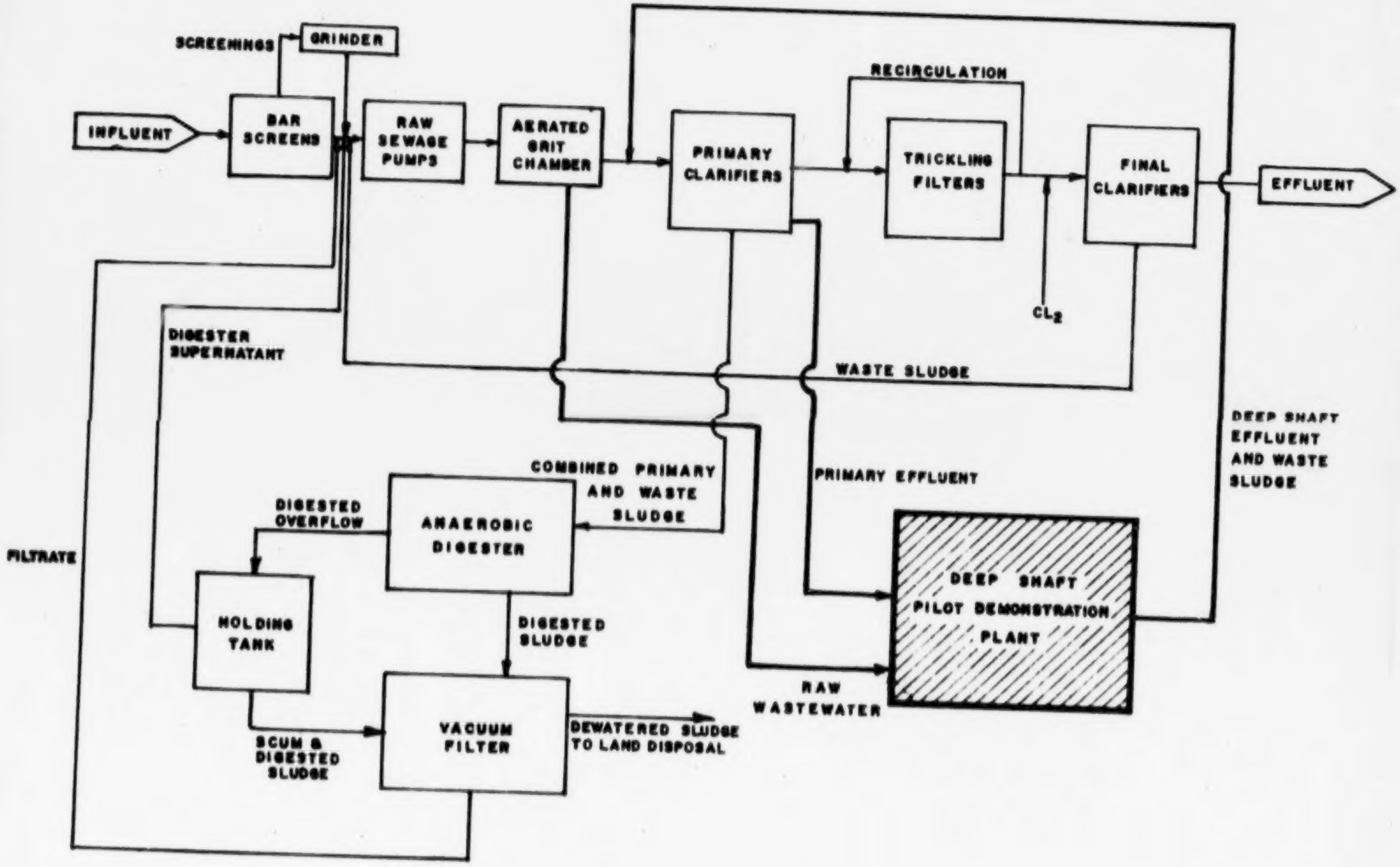


Figure 5. Flow diagram of Ithaca's existing wastewater treatment plant.

TABLE 1. DESIGN CRITERIA FOR ITHACA DEEP SHAFT DEMONSTRATION SYSTEM

Parameter	Flotation Clarification Mode	Gravity Clarification Mode
Bioreactor		
Nominal design flow, m^3/day	757	379
(mgd)	(0.2)	(0.1)
MLSS, mg/l	10,000	5,000
SRT, days	2	2
F/M loading, kg BOD_5/day/kg MLVSS	0.75	0.75
Volumetric organic loading, kg BOD_5/day/m^3	5.54	2.77
(lb BOD_5/day/1000 ft^3)	(346)	(173)
Detention time, min		
nominal (Q)	39	78
actual (Q + R)	24	39
Solids Separation Unit		
Surface overflow rate, m^3/day/m^2	20.1	10.1
(gpd/ft^2)	(494)	(247)
Mass loading, kg TSS/day/m^2	321	103
(lb TSS/day/ft^2)	(66)	(21)
Return sludge flow rate, % of Q		
float recycle	20	N.A.
bottom recycle	40	100
Return sludge concentration, % TSS		
float solids	5	N.A.
bottom solids (intermittent)	1	1-2
Waste activated sludge,		
kg TSS/kg BOD_5 removed	0.75	0.75
kg VSS/kg BOD_5 removed	0.45	0.45
kg TSS/day	77	39
(lb TSS/day)	(170)	(85)

The Deep Shaft reactor at Ithaca was installed with conventional drilling equipment using reverse mud circulation. Carbon steel shafts were utilized for the exterior casing. These shafts were grouted with sulfate resistant cement to allow isolation from the surrounding geological formation.

DESCRIPTION OF PILOT PLANT FACILITIES

A schematic of the Deep Shaft flotation-mode pilot plant evaluated at Ithaca was presented in Figure 4. Degritted raw wastewater or primary effluent was pumped from the main treatment plant to a splitter box located in the pilot plant building. Two pumps were available to supply the influent, each having a capacity of 0.95 m^3/min (250 gpm). The splitter box consisted of a tank with two exit pipes. One of the exit pipes carried wastewater to the influent trough of the Deep Shaft. The flow rate through this pipe and to the shaft was controlled by a pneumatically-operated valve. This valve could be adjusted to provide a constant influent flow rate to the Deep Shaft pilot plant or varied automatically in a diurnal flow pattern. Excess influent flow overflowed the splitter box through the second exit pipe to a sump within the building.

It was necessary to install bar racks in the influent trough since screenings removed from the raw wastewater flow at the main plant were ground and dumped back into the flow. A Parshall flume installed in the influent channel downstream of the bar racks was used to measure the influent flow. An electronic probe located within the wall of the flume converted the height of influent wastewater flowing through it into a signal that was transmitted to a control panel. Depending on the mode of operation, either constant or programmed diurnal, these signals were used to control the amount of flow allowed to enter the influent trough by opening or closing the influent valve. These signals could also be used to control the wastewater samplers and polymer and alum metering pumps.

From the Parshall flume, the wastewater flowed into the trough on the influent end of the flotation tank and mixed with the floating solids being skimmed off the top of the flotation tank. Combined influent flow and return float solids then entered a holding tank adjacent to the shaft. Solids that sank to the bottom of the flotation tank were pumped to the influent flow line at a point ahead of the trough at the front end of the flotation tank. From the bottom of the holding tank, influent wastewater and return solids were piped into the D_2 section of the shaft.

The steel shaft casing had an inside diameter of 44 cm (17.25 in) and a depth of 136 m (446 ft). The inner concentric primary downcomer had an outside diameter of 20 cm (8 in.) for slightly less than the top half of the shaft, 30 cm (11.75 in.) for the remainder of the shaft, and a depth of 133 m (436 ft).

The annulus formed between the outer casing and the inner primary downcomer constituted the primary riser. Excluding the head tank, the volume of Ithaca's shaft was 20.5 m^3 (5,418 gal).

The beginning of the secondary downcomer (D_2) was located about 3 m (10 ft) below the base of the head tank and ran within the primary riser (R_1) to a depth of 61 m (200 ft). The short D_{2U} secondary riser sections, which were connected to the D_2 downcomer, discharged influent wastewater and return sludge into the R_1 primary riser about 15 m (50 ft) up from the bottom of the D_2 section. The opening to the secondary riser mixed liquor withdrawal pipe (R_2) was also positioned at the 61-m (200-ft) level within the primary riser. Air was injected at two depths: 55 and 60 m (180 and 196 ft) from the base of the head tank to the primary downcomer (D_1) and secondary risers (D_{2U}), respectively. Figure 2, previously presented, will assist the reader in comprehending shaft internal geometry.

At the average design flow of 757 m^3/day (200,000 gpd), the hydraulic retention time in the shaft was approximately 39 min. Air was supplied to the shaft from a 15-kW (20-hp) air compressor through three lines, one serving the downcomer and two serving the two riser sections.

The head tank on top of the shaft was designed for a pressure of 7,000 kgf/m^2 (10 psig) and operated at 2,800 kgf/m^2 (4 psig). Off gases plus foam generated within the reactor overflowed the head tank and were piped into the adjacent oxidation tank. The connecting pipe was submerged approximately 3 m (10 ft) below the water surface in the oxidation tank. This liquid head provided the back pressure in the head tank to force the aerated mixed liquor through the secondary riser withdrawal pipe (R_2) and out of the shaft. Off gases rose through the liquid and were vented to the atmosphere. Foam carried over from the head tank to the oxidation tank was partially treated and then recycled back to the holding tank for subsequent treatment in the shaft.

Mixed liquor was discharged from the shaft through the secondary riser, bypassing the head tank, directly into a swirl tank. Here sufficient detention time was provided (10 to 15 sec at average flow) to strip any large air bubbles that would disrupt flotation. A second function of the swirl tank was to control the liquid level in the head tank. This function was to be accomplished by partially closing a plug valve in the bottom of the swirl tank and diverting a portion of flow back into the holding tank.

Aerated mixed liquor was piped from the swirl tank into the flotation tank. The dimensions of the flotation tank were 3.4-m (11.25-ft) wide and 11.0-m (36-ft) long with a side water depth of 4.0 m (13 ft). The surface area was approximately 37.6 m^2 (405 ft^2). The tank was equipped with both top and bottom variable-speed scrapers.

Floating solids were drawn towards the front end of the flotation tank and collected on the beach and pushed over into the influent trough. There the solids mixed with the influent and flowed to the holding tank. Float solids were wasted through a hole in the beach. The valve to control wasting was operated automatically at preset timed intervals or manually. Sink solids were collected by bottom scrapers and a screw conveyor and returned to the influent flow by a variable-speed pump. Sink solids were wasted by opening a valve on the discharge pipe of the sink recycle pump. Both float and sink waste solids were collected in an aerated and mixed waste sludge measurement tank. Periodically these waste solids were pumped to the building sump for subsequent pumping back to the main plant.

Clarified liquid overflowed an adjustable weir at the end of the flotation tank into an effluent trough. Effluent was piped from there into the building sump for return to the main plant.

The sump acted as a collection tank for diverted influent flow, waste sludge solids, clarified effluent, and all material washed down floor drains. An emergency overflow pipe from the holding tank to the sump was also provided to bypass the Deep Shaft unit if the peak hydraulic capacity of the system was exceeded. The contents of the sump were pumped by one of two submersible pumps into a trough at the end of the aerated grit chamber serving the main plant. Usually one pump handled the entire flow; however, on occasions, the level in the sump rose too rapidly and the second pump automatically switched on.

The system for polymer addition consisted of two polyethylene tanks, one for mixing and one for storage of the feed solution. Two pumps, both variable stroke and speed, were available for delivery of the liquid polymer to the mixed liquor just prior to entering the flotation tank. A similar arrangement was provided for the alum. The alum solution, however, was pumped from the feed tank directly into the influent trough just upstream of the Parshall flume.

MAJOR PILOT PLANT MODIFICATIONS

The raw wastewater sidestream takeoff for the demonstration plant was located near the exit of the aerated grit chamber. During the startup period initiated October 8, 1979, it was found that the effects of recirculated flows of digester supernatant, which contributed high slug loadings of suspended solids, BOD_5, and COD to the Ithaca raw wastewater, reached the shaft bioreactor influent virtually undamped and at concentrations far in excess of those encountered with normal sludge processing systems. To take advantage of the solids removal capacity of the main plant's primary clarifiers, it was decided to install the primary effluent feed line, initially thought of as an optional wastewater source to be utilized during planned experimental phases. During the 5- to 6-hr period of the day, referred to as "dumps", when digester supernatant was recirculated back to the headworks of the Ithaca plant, the shaft influent source was switched from degritted raw wastewater to primary effluent.

The pilot plant was shut down on December 7, 1979, and installation of the primary effluent feed line was initiated. During this period of shutdown, modifications were also made to the flotation tank. An internal recirculation line was installed at a point approximately mid-height of the flotation tank and ran from there to the holding tank. The purpose of this recirculation line was to provide a make-up liquid flow to maintain a constant head tank liquid level. With the installation of the make-up liquid recirculation line, the swirl tank plug valve and automatic head tank level controls were eliminated.

This internal recirculation line was later modified on August 27, 1980. A minor external piping change was made such that the bottom solids could be returned to the holding tank by gravity. Recirculation of the flotation tank contents from mid-height of the tank was then abandoned. However, due to problems in controlling the rate at which sink solids were recycled to the holding tank, a pneumatically-controlled pinch valve was installed on the gravity return line. Increasing the air pressure to the pinch valve restricted the valve opening and, therefore, reduced the sink recycle rate. A solenoid was installed on the air supply line such that periodically the pinch valve would open completely and then return to its preset opening. This periodic flushing was provided to reduce the possibility of the pinch valve plugging. The sink recycle pump was maintained as an alternate means of sink solids recycle and for wasting of sink solids.

During the shutdown period from December 7, 1979, to May 4, 1980, an additional modification was made. Originally, compressed air supplied to both of the risers was controlled by only one rotameter. Prior to entering the shaft, the air supply was split. However, it was unknown if air was equally distributed to each of the risers. This situation was corrected by the installation of an additional air supply line and rotameters on each of the air supply lines serving the riser sections.

The last major modification to the pilot plant was the widening of and installation of three additional bar racks in the influent trough between the splitter box and Parshall flume. This modification decreased the number of rags entering the Deep Shaft bioreactor, especially during those periods when operators were not in attendance and the two original racks would frequently plug and overflow to the reactor, and reduced the potential for developing partial shaft blockages and flow restrictions. The installation of additional bar racks was completed on February 9, 1981.

SECTION 5

DESCRIPTION OF EXPERIMENTAL PROGRAM

PROJECT ORGANIZATION

The principal roles of the three parties (City of Ithaca; Stearns & Wheler, Engineers and Scientists; and Eco Technology, Division of C-I-L Inc.) involved in this project, based on the original cooperative agreement application to the U.S. EPA, were:

City of Ithaca - The City provided operating personnel to run the pilot plant on a day-to-day basis, including daily process tests and routine maintenance. The pilot plant was constructed on land owned by the City of Ithaca in the vicinity of their existing wastewater treatment plant. A portion of the laboratory work was performed by City personnel, while the remainder was performed by an independent commercial laboratory.

Stearns & Wheler, Engineers and Scientists - Stearns & Wheler was responsible for supervising plant operation and evaluating Deep Shaft performance.

Eco Technology - Eco Technology was responsible for construction of the Deep Shaft pilot plant. Eco Technology provided process and project expertise with regard to various aspects of the system as well as startup assistance and operational training for Stearns & Wheler and City personnel.

Operational problems, equipment problems, and extended bypassing at the main plant resulting in extended periods of pilot plant downtime; manpower shortages and needed plant modifications necessitated a request for an amendment to the original cooperative agreement. The agreement was amended to cover

1. a time extension to complete the project,
2. additional funds to provide a Resident Project Coordinator, instead of several part-time operators, for the remainder of the study,

3. additional funds for engineering, fabrication, and installation of larger influent wastewater screens in the Deep Shaft building, and

4. additional funds to allow the proprietor of the process to supervise plant operation and to perform analytical testing for a 3-mo period.

The request for funding of a Resident Project Coordinator was based upon the need to provide full-time rather than part-time staffing for the project. In particular, the following factors were involved:

1. The initial allotment of 4 hr/day of operational manpower required to operate the pilot plant was inadequate.

2. Staffing requirements at the Ithaca Sewage Treatment Plant did not allow plant operators to provide adequate attention to the pilot plant as well as the City's treatment plant. During evening shifts and weekends, only one operator was available to attend to both plants and his main responsibility was to the main treatment plant. When an emergency arose at the main plant, the pilot plant had to be left unattended until other operators were called in and/or loaned from the main treatment plant.

3. Rotating shift schedules at the main treatment plant resulted in operation of the pilot plant by several operators at various times. The irregular schedule created communication and coordination problems among the operators.

One of the City's trained operators was assigned as a full-time Resident Project Coordinator whose sole responsibility was to the pilot plant. The Resident Project Coordinator routinely provided 40 hr/wk to the pilot plant and was authorized to provide an additional 8 hr/wk of overtime as necessary. The Resident Project Coordinator performed most of the laboratory tests previously performed by City personnel. He was also responsible for coordinating the efforts of the City's plant staff as needed.

As a result of the cooperative agreement amendment, Stearns & Wheler was directly responsible for overall pilot plant supervision, including troubleshooting plant operation, from August 1980 through April 9, 1981.

The cooperative agreement also increased the duties of the proprietor, Eco Technology. Eco Technology supervised plant operation for the last 3 mo (June-Agust 1981) of the experimental program. During this time period, Eco Technology provided duplicate analytical services as well. Stearns & Wheler acted as technical auditor, and samples were split for analytical testing on a routine basis.

EXPERIMENTAL PROGRAM

Under the conditions of the original agreement, the pilot plant study consisted of a 2-mo startup phase and a two-phase experimental program lasting approximately 16 mo. Originally, the program consisted of 42 wk of phased evaluations in the flotation clarification mode and 22 wk in the gravity clarification mode. The evaluation program was designed to address the objectives listed in Section 1. The original schedule and description of tasks to be accomplished for the startup and experimental program phases are contained in Table 2. The experimental program was established to test the system in both modes of operation under a variety of conditions including constant flow, diurnal flow, hydraulic overloading, cold weather operation, and alum addition. The flotation mode of operation was also to be tested with polymer addition and treating primary effluent.

Because of numerous unforeseen problems during the course of the evaluation period, the experimental program had to be revised several times. The major revision in the program was to eliminate the sedimentation mode of operation to allow more time for evaluation of flotation clarification as the preferred mode of operation. A summary of the final revised experimental program is presented in Table 3.

Analytical Program

The analytical program included sampling of system influent, system effluent, mixed liquor, float solids recycle and waste, and sink solids recycle and waste. Automatic composite samplers were installed to sample system influent and effluent. These samplers were integrally wired to the influent controller so that flow-related composite samples could be obtained during the diurnal flow period.

Analytical work generated during the evaluation program through the pilot plant shutdown period in April 1981 was shared between Ithaca's treatment plant laboratory and a commercial laboratory. Prior to the assignment of the Resident Project Coordinator, City personnel were responsible for conducting

TABLE 2. ORIGINAL EXPERIMENTAL PROGRAM

Project Month	Phase	Description of Work
	Startup	
1		- Initiate startup procedures for flotation mode.
		- Monitor equipment operation and troubleshooting as necessary.
2		- Commence analytical testing when steady-state conditions are reached.
	Experimental Program	
3	Flotation Mode	- Collect data at $Q = 757\ m^3/day$ (200,000 gpd) of raw wastewater.
4-7		- Collect data under diurnal flow operating conditions.
8		- Conduct special sampling studies.
		- Begin alum addition for phosphorus removal.
9-10		- Time permitting, vary the raw wastewater flow to stress the system.
11	Sedimentation Mode	- Switch to clarifier operation at $Q = 379\ m^3/day$ (100,000 gpd) of raw wastewater.
		- Monitor equipment operation and troubleshooting as necessary.
12		- Collect data when steady-state conditions are reached.
13-15		- Collect data under diurnal operating conditions.
16		- Conduct special sampling studies.
		- Begin alum addition for phosphorus removal.
17-18		- Time permitting, conduct additional testing of flotation mode on primary effluent and/or trickling filter effluent.

TABLE 3. REVISED PROJECT SCHEDULE

Dates	Duration (wk)	Description
		Startup Phase
10/08/79 - 11/12/79	3	Startup by Eco operators and operator training
11/13/79 - 12/06/79	5	Operation turned over to city
12/07/79 - 05/04/80	21	Plant shutdown for modifications and bypassing at main plant
05/05/80 - 05/17/80	2	Restart by Eco operators
		Experimental Phase
05/18/80 - 07/11/80	8	Constant flow - raw wastewater
07/12/80 - 08/03/80	3	Diurnal flow - raw wastewater
08/04/80 - 10/20/80	11	Diurnal flow - raw wastewater*
10/12/80 - 02/08/81	15	Diurnal flow - primary effluent*
02/09/81 - 04/10/81	9	Diurnal flow - raw wastewater*
04/11/81 - 05/30/81	7	Plant shutdown for bypassing
05/31/81 - 08/28/81	13	Diurnal flow - raw wastewater*

* With Resident Project Coordinator

1. total and volatile suspended solids analyses on grab samples of mixed liquor, sink solids recycle flow, and waste sludge,
2. total suspended solids analysis on 24-hr composite samples of pilot plant effluent,
3. DO determinations on grab samples of mixed liquor and pilot plant effluent,
4. temperature and pH determinations on grab samples of influent, mixed liquor, and pilot plant effluent, and
5. cylinder tests on grab samples of mixed liquor, flotation tank feed, and sink solids recycle.

In addition, Ithaca operators were responsible for recording influent flow rates to the pilot plant.

The Resident Project Coordinator, assigned on August 4, 1980, performed the total and suspended solids analyses previously performed by City personnel responsible for operating the main plant. However, the City operators were still responsible for conducting DO, pH, and temperature determinations as well as cylinder tests. The Resident Project Coordinator was also responsible for conducting

1. total BOD_5 analyses on 24-hr composite samples of pilot plant influent and effluent,
2. total suspended solids analyses on 24-hr composite samples of pilot plant effluent, and
3. on occasions, as deemed necessary, total and volatile suspended solids analyses on grab samples of the float recycle flow and soluble BOD_5 analysis on 24-hr composite samples of pilot plant effluent.

The responsibilities of the commercial laboratory, prior to the scheduled shutdown period for bypassing at the main plant in April and May 1981, included

1. total and soluble BOD_5 and COD analyses on 24-hr composite samples of pilot plant influent and effluent,
2. total and volatile suspended solids analyses on 24-hr composite samples of pilot plant influent and effluent,

3. weekly nitrogen series analyses on 24-hr composite samples of pilot plant influent and effluent, and

4. periodic analyses for orthophosphorus, total phosphorus, heavy metals, chlorides, and alkalinity on 24-hr composite samples of pilot plant influent and effluent.

During the last 3 mo of the experimental program, analytical duties were shared between the commercial testing laboratory and the Eco Technology Mobile Laboratory, including a number of duplicate analyses.

Analytical Procedures

All analytical procedures performed by the commercial laboratory were in accordance to procedures outlined in Standard Methods for the Examination of Water & Wastewater (1), 14th edition, except as noted.

Biochemical Oxygen Demand - The 5-day BOD (BOD_5) determinations were based upon the procedure outlined in Standard Methods, pages 543-550, employing the azide modification of the Winkler test as described in pages 443-449.

Samples were stored at 4°C for approximately 6 to 54 hr prior to analysis.

Glucose standards were run weekly as part of quality control, and distilled water blanks were routinely run together with samples for the same purpose. Both were run in triplicate.

Prior to October 1980, samples and dilution water blanks were run in triplicate and unseeded. BOD_5 calculations were based upon the 5-day DO uptake while accounting for the dilution water uptake and making appropriate volume adjustments.

Commencing in October 1980, samples and dilution water blanks were seeded with 2 ml of raw influent from a local wastewater treatment plant. Also, at this time, additional checks were run to further substantiate the results. Three sets of triplicate unseeded dilution water blanks were prepared each time samples were to be run. The first set was left unseeded; the second and third sets were innoculated with 10 and 20 ml of seed, respectively. All three sets were run together with the seeded samples and dilution water blanks. BOD_5 results from the additional three sets were manipulated to assess the accuracy of the DO uptake in the seeded dilution water blanks. It was found that results from the additional checks always substantiated results attained from the dilution water blank seeded similarly to the samples.

BOD_5 calculations were based upon the sample DO uptake less the depletion water and seed uptake and adjusted for volume.

Use of the excess ammonia nitrogen procedure for nitrification inhibition in effluent BOD_5 analyses proved to be unreliable and was discontinued.

Samples were filtered through a glass fiber filter (Reeves Angel 934AH) prior to soluble BOD_5 determinations.

Chemical Oxygen Demand - The dichromate reflux method, as presented in Standard Methods, pages 550-554, was the procedure used for all COD determinations with one minor variation. The 30 ml of sulfuric acid reagent were added directly into the Erlenmeyer flask and not through the condenser.

Samples were filtered through a glass fiber filter (Reeves Angel 934AH) prior to soluble COD determinations.

Solids - Both total suspended and volatile suspended solids were determined according to Procedures 208D and 208E as outlined in Standard Methods, pages 94-95. Sample volumes of less than 100 ml were used on samples with a high nonfilterable residue content when filtration time became excessive. Measurements were made on a Sartorious, Model No. 2842 balance accurate to within 0.1 mg. Glass fiber filter paper was Reeves Angel 934AH.

Dissolved Oxygen - DO measurements were taken with a Yellow Springs DO meter, Model No. 57. The instrument was calibrated against the modified Winkler method.

Alkalinity - Total alkalinity was measured as outlined in Standard Methods, pages 278-282, using the potentiometric method. A Corning, Model No. 10 pH meter was used.

Nitrogen - Nitrate (NO_3^--N) and nitrite (NO_2^--N) nitrogen determinations were made according to Standard Methods, pages 423-427 and 434-436, respectively. Samples were analyzed colorimetrically before and after cadmium reduction. The analysis was performed with the aid of a Technicon Auto Analyzer, Model No. II.

Ammonia nitrogen (NH_4^+-N) was determined using the nesslerization method as described in Standard Methods, pages 412-415. Total Kjeldahl nitrogen (TKN) was measured according to Standard Methods, pages 437-440. Ammonia determinations were done as part of the TKN analysis.

Phosphorus - Total phosphorus was measured colorimetrically following a persulfate digestion as outlined in Standard Methods, page 476. Samples were filtered through clean glass fiber filters (Reeves Angel 934AH) for total soluble phosphorus measurements.

Orthophosphorus was determined by the ascorbic acid method as described in Standard Methods, Pages 481-482.

Metals - All metals including Fe, Ni, Mn, Pb, Cd, Zn, Cu, Cr, and Hg were determined by Atomic Absorption Spectrophotometry using an Instrumentation Laboratories aa/ae spectrophotometer, Model No. 551. Both aspiration and furnace techniques were utilized according to the metal concentrations.

Special Tests - Oil and grease was determined by separatory funnel extraction according to U.S.EPA guidelines presented in "Methods for Chemical Analysis of Water and Wastes", 1979 (30).

SECTION 6

PILOT PLANT STARTUP

STARTUP PROGRAM

Eco Technology personnel responsible for startup of the Deep Shaft process began work at the pilot plant site on September 6, 1979. During the next 4 wk, they were occupied with expediting the mechanical completion of the equipment, preliminary testing and calibration of equipment, and hydraulic testing of the bioreactor.

The startup program consisted of four separate periods including

1. Eco operation and operator training, October 8, 1979, through November 12, 1979,
2. operation by personnel from the City of Ithaca, November 13, 1979, through December 7, 1979,
3. pilot plant shutdown for modifications, December 8, 1979, through February 4, 1980, and
4. intermittent treatment of degritted raw wastewater, primary effluent, and recirculated trickling filter effluent due to repairs to aerated grit chamber at main plant and main plant bypassing, February 5, 1980 through May 17, 1980.

Eco Operation and Operator Training

Eco Technology personnel initiated startup procedures for the flotation mode on October 8, 1979, and continued their operation through November 12, 1979. It was not necessary to inoculate the bioreactor with an external supply of sludge. Following the conclusion of 2 days of hydraulic tests, in the course of which the shaft was operated with variable quantities of influent wastewater, an adequate level of MLSS was built up (over 5,000 mg/l) so that treatment of influent began immediately. Although several components of the control and alarm systems were not yet functioning satisfactorily, operation of the pilot plant was continued under careful supervision to troubleshoot problems and debug the equipment.

Eco Technology provided the services of a mobile analytical laboratory at the pilot plant site for the 5-wk period of the startup program. Eco personnel monitored process performance by analyzing composite samples of the influent and effluent for suspended solids and COD. Grab samples of mixed liquor, bottom recycle, and float blanket were also analyzed daily for suspended solids. Additional analyses of ammonia nitrogen and orthophosphorus were performed to determine if adequate nutrients were present in the pilot plant influent.

During this period of operation, Eco formulated a program for training operators from the City's main plant in the operation of the pilot plant. In addition to familiarizing the operators with the Deep Shaft demonstration plant, this program was important because of the relative inexperience of most of the City's operators with activated sludge treatment. The operator training program consisted of two 2-hr training sessions per day for approximately 10 days. The program was devised to familiarize the operators with the fundamentals of biological treatment, sedimentation theory, flow paths and tank liquid levels, plant hydraulics, equipment maintenance, sludge wasting schedules to maintain correct operating parameters, pilot plant controls, process monitoring, and startup and shutdown procedures. Eco personnel also developed a program for troubleshooting operational problems. It soon became evident that the operator training program could not be carried out as planned. Due to manpower scheduling and operational problems at the main plant requiring operator attention, Eco attempted to train the operators when they could be released from their daily responsibilities. This situation resulted in sporadic training sessions, ending with some of the operators being more familiar with the operation of the pilot plant than others.

In addition to the analyses performed by Eco Technology personnel, a commercial laboratory performed analyses on 24-hr composite influent and effluent samples including

1. influent and effluent total BOD_5 and soluble BOD_5,
2. influent and effluent total COD and soluble COD,
3. influent and effluent suspended solids and volatile suspended solids, and
4. influent and effluent total phosphorus, orthophosphorus, and total nitrogen series.

The commercial laboratory commenced analyses of weekly influent and effluent samples on October 16, 1979, approximately 1 wk after Eco personnel began operating the pilot plant and terminated analytical work on December 5, 1979, just prior to the shutdown period.

Operation by City Personnel

The pilot plant was turned over to personnel from the City of Ithaca's main plant on November 13, 1979. In addition to the analytical tests performed by the commercial laboratory, City operators were responsible for performing suspended solids analyses of grab samples of mixed liquor, bottom recycle, and float blanket; suspended solids analyses of 24-hr composite effluent samples; and cylinder tests on samples of mixed liquor and sink recycle.

Following the departure of Eco personnel, it soon became evident that the City operators lacked sufficient experience to maintain the proper wasting balance between float solids and bottom solids. Deteriorating performance was soon evident in increasing effluent suspended solids. In an attempt to simplify wasting operations, Eco prescribed a modification to provide separate control over flotation tank internal fluid recirculation and sink sludge return rates.

The solids loading resulting from the recycle of digester supernatant to the headworks of the Ithaca plant caused problems for operating personnel during startup. The anaerobic digester's mechanical agitator was non-operational. To provide needed stirring in the digester, overflow digester liquor was continuously pumped to a large holding tank and back to the digester. Twice a week (usually Sunday and Thursday nights), the pump was turned off, solids were allowed to settle in the holding tank, and supernatant was diverted from the tank to the influent wet well, which was then pumped to the plant's grit chamber. These digester "supernatant dumps" lasted 5 to 6 hr and, despite the preceding settling period in the holding tank, contributed high slug loadings of organics and suspended solids to the raw wastewater.

The demonstration plant raw wastewater sidestream takeoff was located near the exit from the grit chamber. Consequently, shaft bioreactor influent received the effect of the "dumps" virtually undamped. Influent total COD and suspended solids concentrations increased 10 to 20 fold during the 5- to 6-hr "dump" periods. The solids were highly mineralized (50 percent ± volatile fraction) and, therefore, did not increase influent total BOD_5 by the same proportion. This shock condition made it impossible to hold system biomass inventory at prescribed levels, often increasing MLSS to 15,000 mg/l and above. The digester supernatant was also observed to have a temporary inhibitory impact on mixed liquor respiration rates (19).

The primary effluent feed line was initially thought of as an optional wastewater source to be utilized only during planned experimental phases. Following the startup experiences, a joint decision was made to switch the shaft influent source from degritted raw wastewater to primary effluent during the 5- to 6-hr supernatant "dump" periods. By taking advantage of the solids removal capacity of the main plant primary clarifiers, it was anticipated that the shaft influent pollutant levels would not increase so dramatically and rapidly. Although the pilot system exhibited excellent recovery capability, it was believed that coping with frequent high strength supernatant discharges would distort the major emphases of the project and disrupt the accurate recording and analysis of critical data such as excess sludge production and flotation tank response to routine variations in loading.

To conserve operating funds until meaningful results could be obtained, it was decided to shut down the plant on December 8, 1979, to carry out the proposed modifications.

Intermittent Treatment

The pilot plant was restarted under Eco supervision on February 5, 1980. However, due to spring thaw conditions and the main plant's inability to handle the large quantities of inflow entering the City's wastewater collection system, it was necessary to bypass some of the wastewater entering the influent pump station. Depending on the magnitude of the inflow entering the system, the bypass line was opened at times such that no flow reached the aerated grit chamber. During these times, the influent line was switched to primary effluent. However, since no raw wastewater was reaching the grit chamber, only those dilute flows recirculated from the trickling filter to the primary settling tanks were being pumped to the pilot plant. This bypassing situation persisted through the end of April 1980.

On April 29, 1980, the aerated grit chamber was taken out of service for repairs. Again the pilot plant influent line was switched to primary settling tank effluent until completion of repairs on May 7, 1980.

No sampling was conducted during this period of intermittent treatment. Sampling was resumed on May 18, 1980, with the beginning of the experimental program.

SUMMARY OF STARTUP RESULTS

The 60 days (36 Eco, 24 City) of operation prior to the shutdown period were comprised of 3 days at 70 percent of design flow, 53 days at the flotation mode design flow of 757 m^3/day (200,000 gpd), 2 days at 150 percent of design flow, and 2 days at reduced flow to repair equipment. Analytical results reported by the commercial laboratory for these days are presented in Appendix A. Analytical results from the mobile laboratory operation have been reported by Eco Technology in its commissioning report (19).

The commissioning report covers the operation of the pilot plant during the entire startup program, including that period when City personnel were in charge. In addition to the analytical results reported by Eco, a portion of the analytical results reported by the commercial laboratory were incorporated in the report including

1. influent and effluent BOD_5 data from October 16, 1979, to November 29, 1979,

2. influent and effluent suspended solids and COD data from November 1, 1979, to November 12, 1979, for those days that Eco reported no results for these parameters, and

3. influent and effluent suspended solids and COD data from November 13, 1979, to November 29, 1979.

Operating results reported in the commissioning report for the 36 days Eco was in charge of the startup program are summarized below:

1. Effluent total BOD_5 averaged 15 mg/l versus 136 mg/l entering for a system removal of 89 percent. Effluent soluble BOD_5 averaged 6 mg/l.

2. Suspended solids removal averaged 91 percent with 30 mg/l in the effluent against 334 mg/l in the system influent. These results were achieved, with the exception of 3 trial days, without the use of a polymeric flocculation aid.

3. An average effluent total COD concentration of 66 mg/l was achieved. Based on an average system influent total COD of 485 mg/l, removal averaged 86 percent for the period.

4. Effluent soluble COD mirrored the acclimatization of the Deep Shaft biomass, dropping from an initial level of 100 to 110 mg/l to 50 to 60 mg/l after 2-1/2 wk to 20 to 30 mg/l after 3-1/2 wk.

5. Suspended solids in the float blanket (top return) generally ranged from 8 to 8.5 percent; underflow solids (bottom return) ranged from 2.5 to 3.5 percent.

6. Due partially to anaerobic digester supernatant solids returned to the main plant headworks, the reactor biomass developed rapidly, reaching an operating MLSS concentration of 10,000 mg/l within 2 days.

Operating results for the 24 days during which personnel from the City of Ithaca were responsible for operating the pilot plant are summarized below:

1. Effluent total BOD_5 average 30 mg/l versus 117 mg/l entering for a system removal of 74 percent.
2. Suspended solids removal averaged only 66 percent with 121 mg/l in the effluent against 360 mg/l in the system influent.
3. The influent total COD concentration averaged 434 mg/l, and the effluent total COD concentration averaged 151 mg/l, yielding a system reduction of 65 percent for the period.

These results represented a significant decrease in effluent quality compared to those for the period that Eco personnel operated the pilot plant.

The semi-weekly digester "supernatant dump" policy produced the following effect on Deep Shaft performance. Effluent suspended solids increased from a typical background level of 30 mg/l ± to peaks of 40 to 80 mg/l. Effluent total COD exhibited corresponding increases, peaking at concentrations ranging from 100 to 200 mg/l. Recovery to steady-state effluent quality generally occurred within 12 to 24 hr of the initiation of the shock loadings. Recovery time was minimized by careful operation and anticipation of the "dumps".

Float quality was also impaired by the shock loadings, thinning out from a normal thickness of about 60 cm (24 in.) to 15 cm (6 in.) or less. A 3-mg/l dose of cationic polymer was beneficial in helping to maintain desirable float characteristics during the "dumps", but at the expense of increased effluent suspended solids, probably due to rendering more flocs neutrally buoyant. The float blanket also typically recovered to "pre-dump" stability within 12 to 24 hr.

The difficulties that could be anticipated over a long-term evaluation period from the digester supernatant sludge became more evident when the demonstration plant was turned over to the City. For the 24 days from November 13 through December 7, 1979, with City operators in control, effluent quality deteriorated quite rapidly. Effluent deterioration was attributed to the lack of operator experience in adjusting process sludge wasting requirements, particularly in response to the supernatant discharges.

SECTION 7

EXPERIMENTAL RESULTS

CHRONOLOGICAL OVERVIEW OF EXPERIMENTAL PROGRAM

After modifications were made to the pilot plant and the staffing arrangements were altered, the experimental program was initiated in May 1980. With one operator charged with the primary responsibility for operating the pilot plant on a daily basis, except weekends, Eco Technology personnel were better able to provide more intensive training to selected operators concerning operational control of the Deep Shaft process. The revised staffing arrangements resulted in improved plant attention and performance, but eventually were found to still be unsatisfactory.

As a result of numerous unforeseen problems and occurrences encountered throughout the course of the study after the pilot plant was restarted, the project schedule had to be revised several times. These problems and events included inadequate operator attention and control, mechanical breakdowns, instrumentation malfunctions, operating problems at the main plant, excessive foaming, and occasionally partial shaft blockages. In general, the Deep Shaft process was often adversely affected by external factors and representative data could not be obtained. Until the spring of 1981, there were relatively few time periods that a consistent, routine operation was established to allow a fair evaluation of the process. Each of these factors and their effect on pilot plant operation and performance will be discussed in more detail later in this section. The project schedule was revised also to reflect a joint decision by all concerned parties to eliminate the sedimentation mode from the evaluation program. It was determined and agreed that the study should focus on flotation clarification as an integral part of the Deep Shaft process. Sedimentation clarification requires a degassing step prior to sedimentation and, because of a more dilute sludge recycle, requires a larger shaft volume to achieve the same solids inventory. Consequently, the Deep Shaft process coupled with sedimentation loses many of its inherent advantages and probably is not economically competitive with conventional activated sludge systems.

Table 4 contains a chronological overview of the evaluation period after all project schedule revisions. The table contains the dates of operation, operating characteristics, and a brief summary of problems and major events for each mode of operation. Various modes of operation evaluated included combinations of raw wastewater versus primary effluent, constant versus varying (diurnal) flow rates, polymer addition as a flotation aid, and alum addition for phosphorus removal. The primary focus of the study was to evaluate process performance in treating screened and degritted raw wastewater under a diurnal flow pattern without polymer addition, as illustrated in Table 4 by the amount of time the pilot plant was operated in that mode.

The experimental program can be divided chronologically into three phases of operation: first raw wastewater phase, primary effluent phase, and second raw wastewater phase.

First Raw Wastewater Phase

The first raw wastewater phase began May 18, 1980, and ended October 20, 1980. During this phase, the pilot plant was operated under a constant influent flow rate with and without polymer addition and under a predetermined diurnal flow pattern without polymer addition. In the constant flow period, the influent flow rate controller was set at approximately 757 m^3/day (200,000 gpd). With the addition of the primary effluent line, the operators were instructed to switch the pilot plant influent flow from raw wastewater to primary effluent during digester dump periods. With the addition of the gravity sidearm return line from the flotation tank to the holding tank to recycle flow back to the shaft, the sink recycle pump was still used to return sink solids to the system and to waste sink solids. The height of the sidearm return line was established to maintain a total flow of approximately 1,666 m^3/day (440,000 gpd) to the shaft comprised of the following:

Influent = 757 m^3/day (200,000 gpd)
Sink recycle = 341 m^3/day (90,000 gpd)
Float recycle = 76 m^3/day (20,000 gpd)
Sidearm return = 492 m^3/day (130,000 gpd)

Total = 1,666 m^3/day (440,000 gpd)

The purpose of the sidearm return was to provide one function previously accomplished by the swirl tank in supplying make-up liquid to return to the shaft. The level of the sidearm return draw-off pipe was at approximately mid-depth of the flotation tank, therefore, the return flow to the shaft was very dilute in solids. The return of biological solids to the shaft was still accomplished primarily by the float and sink recycle flows.

TABLE 4. CHRONOLOGICAL OVERVIEW OF EXPERIMENTAL PROGRAM

Date	Pilot Plant Description	Remarks
5/18/80-6/9/80	Raw wastewater, constant flow, polymer	Initiation of experimental program Revised staffing arrangements Clogging of influent line and pumps
6/10/80-7/11/80	Raw wastewater, constant flow, no polymer	Sink recycle pump breakdown Several power failures Compressor and air rotameter malfunctions
7/12/80-10/20/80	Raw wastewater, diurnal flow, no polymer	Flow controller malfunctions Spill pot and holding tank overflows Staffing arrangements revised 8/4 - Resident Project Coordinator assigned under supervision of Stearns & Wheler Oxidation tank overflow line plugged Sink recycle line plugged Influent pumps plugged Variable head tank pressure Plant modifications Shaft stalls, reversals, and overflows Control panel malfunctions Excessive foaming Shaft partial blockage
10/21/80-10/26/80	Raw wastewater, constant flow, no polymer	Sampling discontinued 10/21 Shaft stalls, reversals, and overflows

(continued)

TABLE 4. (continued)

Date	Pilot Plant Description	Remarks
10/27/80-11/30/80	Primary effluent, constant flow, no polymer	Controlled reversal to dislodge blockages Sampling resumed 11/9 Sampling discontinued 11/21 Excessive foaming
12/1/80-12/12/80	Primary effluent, diurnal flow, no polymer	Sampling resumed 12/7 Excessive foaming
12/13/80-1/12/81	Primary effluent, diurnal flow, polymer	Polymer addition to control foaming Automatic sludge wasting module malfunction Polymer dosage diluted accidentally 12/31-1/5 Polymer dosage <0.5 mg/l to 3.0 mg/l
1/13/81-1/23/81	Primary effluent, diurnal flow, alum	Polymer added 1/13-1/16
1/24/81-1/30/81	Primary effluent, diurnal flow, no polymer	Screw conveyor belt broken - no sink wasting possible
1/31/81-2/8/81	Primary effluent, diurnal flow, polymer	Sampling discontinued 1/31 Plant shut down to install additional bar screens
2/9/81-2/13/81	Raw wastewater, diurnal flow, polymer	No sampling Reacclimation to raw wastewater

(continued)

TABLE 4. (continued)

Date	Pilot Plant Description	Remarks
2/14/81-4/10/81	Raw wastewater, diurnal flow, no polymer	Sampling resumed 2/19 Digester problems at main plant Shaft partial blockage - shut down for cleaning 3/20-3/23 Constant flow 3/27-3/29
4/11/81-5/17/81	Plant shutdown	Sampling discontinued 4/11 - plant shut down for bypass season
5/18/81-5/30/81	Plant startup	Resident Project Coordinator under direct supervision of Eco Technology
5/31/81-8/28/81	Raw wastewater, diurnal flow, no polymer	Sampling resumed 5/31 Screw conveyor drive belt broken Compressor malfunctions Heavy solids loadings from main plant Experimental program concluded 8/28

The process was operated for approximately 3 wk with polymer addition (11 days at 2.8 mg/l, 9 days at 1.5 mg/l). The influent BOD_5 strength was low during this time period compared to typical domestic wastewater as a result of infiltration and inflow into the collection system. The suspended solids level was much higher in relation to the BOD_5 concentration than expected for domestic wastewater because of the digester dumps. Although the influent was switched to primary effluent during these dump periods, digester solids were not eliminated from the pilot plant influent. Frequently, the primary settling tanks were overloaded during the dump periods and solids were drawn into the pilot plant intake piping. In addition, the main plant's sludge holding tank was partially drained from mid-depth for short time periods throughout the week, during which time the pilot plant influent was rarely switched to primary effluent.

After establishing a good float blanket with polymer addition at 2.8 mg/l, the dosage was reduced to 1.5 mg/l. After several days of operation, polymer addition was eliminated altogether to evaluate process performance without a flotation aid. It was observed up to this point that although a good thick float blanket would form in the morning, it gradually thinned out in the afternoon and disappeared at night. Consequently, the operator was reluctant to waste float solids and sink solids were the primary source of sludge wasting. A good float blanket was maintained most of the time without polymer addition, and effluent quality was not adversely affected. The plant operated for approximately 1 mo under constant flow without polymer addition before changing to a diurnal flow pattern.

A number of mechanical problems typical of early-stage pilot plant operations were encountered during the raw wastewater constant flow period. Among these were compressor malfunctions, breakdown of the sink recycle pump, air rotameter and diverter valve malfunctions, and control panel malfunctions. Several power failures occurred during this time period, resulting in pilot plant shutdowns and restarts. Although the process was adversely affected several times as a result of these occurrences and mechanical problems, the impacts were short term and the process quickly recovered.

On July 10, 1980, an influent flow rate controller was placed in operation to simulate a diurnal flow pattern. The average daily flow remained at approximately 757 m^3/day (200,000 gpd) with sustained peaks of 1,136 m^3/day (300,000 gpd) for up to 8 hr during the day and 379 m^3/day (100,000 gpd) for up to 8 hr at night. The pilot plant continued to operate on raw wastewater with no polymer addition. Piping modifications were made to the sidearm return line to allow sink solids to be returned to the holding tank by gravity similar to an Eco III design. Thus, the sidearm return of dilute mixed liquor was eliminated and the sink recycle pump was intended to be used only for sludge wasting. The flapper valve on the sink return line was adjusted to maintain a total flow including influent flow and all recycle streams in the range of 1,514 to 1,666 m^3/day (400,000 to 440,000 gpd). As the level in the holding tank varied with the diurnal influent flow pattern, the gravity sink return flow rate increased or decreased in inverse proportion to the influent flow rate. The plant was operated in this fashion for the next 3 mo.

In the beginning of August 1980, another change was made in staffing arrangements for the pilot plant. One of the City's operators was assigned to the pilot plant on a full-time basis as the Resident Project Coordinator. It was believed that a full-time operator was needed to provide the attention the pilot plant required, particularly in light of the numerous equipment breakdowns and malfunctions encountered. Under the previous staffing arrangements, the City's operators did not have time to adequately oversee the operation of the pilot plant as well as the City's plant, especially during evenings, weekends, and holidays when only one operator was on duty. It was also believed (and later verified) that improved operation would be achieved by making one operator solely responsible for the pilot plant. It was his responsibility to provide coordination with the other operators and with main plant operations. In addition to operating the pilot plant, the new full-time operator was responsible for running daily control tests and analytical tests to monitor effluent quality on a daily basis.

Additional modifications were made during this time period. The sink recycle gravity return line plugged several times when the flapper valve was throttled down to reduce the return flow rate. It was believed that the total flow to the shaft and the solids loading to the flotation tank were excessive and adversely affecting the process. A pneumatically-operated pinch valve was added to the gravity return line to throttle the flow; however, the line continued to plug frequently. Eventually, a solenoid was installed to periodically open the pinch valve and flush out accumulated solids. Other modifications included the addition of rigid piping from the oxidation tank to the holding tank to reduce the potential of that line plugging and to maintain a constant head tank pressure. The spill pot and associated overflows were thereby eliminated.

During the diurnal flow period, numerous problems were encountered that adversely affected the process and gradually deteriorated effluent quality. These problems included

1. maladjustment of the diurnal flow controller,
2. spill pot overflows prior to modifications,

3. plugging problems in the sink recycle line and the oxidation tank overflow line,
4. head tank pressure fluctuations,
5. control panel malfunction,
6. overflowing of the holding tank causing building flooding,
7. severe foaming throughout system, and
8. partial blockage of one D_2U riser section.

Because of the numerous recurring problems encountered during this time period, a normal routine operation was never established and representative data were not obtained. The plant was shut down and restarted a number of times as a result of power failures and equipment problems. The system became more and more prone to upset. It was eventually determined that one of the D_2U riser channels within the shaft was partially blocked, causing the shaft to stall at times and resulting in overflows. It is unknown at what point the partial blockage occurred because of other complications. Severe foaming throughout the system was encountered during this time period as well, which contributed to stalls and overflows. The source of the excessive foaming was never determined but suspected to be a local industry discharging acid wastes and detergents to the municipal collection system.

It was suggested that hydraulic overloading could be a contributing factor to shaft stalling. To test this possibility, it was decided to reduce the peak daily flow to 984 m^3/day (260,000 gpd), thereby reducing the total flow to the shaft from 1,666 m^3/day (440,000 gpd) to 1,514 m^3/day (400,000 gpd). Overflows continued even when the system operated at a constant influent flow of 757 m^3/day (200,000 gpd). The possibility of an excessively high F/M loading rate causing the foaming was also considered. The F/M loading was decreased as much as possible by operating the system at the maximum MLSS level achievable. This did not have any visible impact on the system and did not seem to reduce the amount of foaming. It was eventually determined that there must be a partial blockage within the shaft. The sampling program was temporarily suspended while investigating the situation.

As previously discussed, the screenings grinder at the main plant was ineffective in shredding screenings removed from raw wastewater. After grinding, the screenings were discharged back into the plant influent channel. It was apparent that large amounts, up to 19 l (5 gal) per 8-hr shift, of partially shredded rags and other materials were routinely pulled into the pilot plant intake piping from the grit chamber. The intake line in the grit chamber plugged, the influent pumps became clogged every 1 to 2 days, and the gravity sink recycle line was plugged several times. Based on these and other observations, it was concluded that one of the small D_2U channels within the shaft had become partially blocked with rag accumulations.

Primary Effluent Phase

Beginning the last week in October 1980, the pilot plant influent was switched to primary effluent to reduce the intake of rags to the system, believed to be the cause of the partial D_2U blockage. The shaft was deliberately reversed to dislodge any blockages within the D_2U sections. This step proved to be successful. It was decided at this time to initiate the primary effluent phase of the experimental program and not to return to raw wastewater feed until the excessive ragging situation was resolved. The primary effluent phase of the study lasted from November 1980, when the sampling program was resumed, until February 1981. During this phase, the system was evaluated under constant and diurnal flow conditions, with and without polymer addition, and with alum addition for phosphorus removal.

While operating on primary effluent at constant flow (2 wk), the amount of foaming decreased but it was not eliminated and still appeared to be excessive. Although the overflows stopped, the system did not appear to operate properly or as anticipated. The float solids in the flotation tank changed from a grey-brown to a creamy, light brown color. The float solids concentration decreased from approximately 50,000 mg/l to less than 30,000 mg/l. The blanket did not thicken well, and the trailing edge of the blanket was poorly defined. Many flocculant particles were carried over the weirs, deteriorating effluent quality. The sampling program was again temporarily suspended prior to switching to diurnal flow to investigate the situation. It was theorized that the F/M loading was still excessive, thereby causing the foaming. The MLSS level could not be increased because the sludge produced by treating primary effluent did not thicken well. Polymer addition was initiated to maximize the MLSS level by increasing the float blanket thickness and hopefully eliminate the foaming. The addition of polymer was accompanied by a substantial reduction in foaming. Decreased foaming could not be attributed to an increase in the MLSS level, however, as in fact, the MLSS concentration decreased after polymer addition was initiated. The plant influent was switched to diurnal flow, and polymer addition was discontinued. Excessive foaming returned to the system immediately, and effluent quality deteriorated. Polymer addition was again initiated for the sole purpose of controlling foaming. Although the exact mechanism is not known, polymer addition did serve to control foaming tendencies during this time period. The system was operated in this manner for approximately 1 mo. Effluent quality during this period was impaired as many solids were being carried over the weir. It appeared that polymer addition caused some solids to remain suspended that otherwise would have settled to the bottom of the flotation tank.

Alum was added to the flotation tank feed line with and without polymer addition for the dual purpose of removing phosphorus and determining the effect of alum on the system. Alum addition was discontinued after 10 days of operation. The float blanket virtually disappeared as most solids were sinking. Although floating solids were observed in the daily jar tests, apparently the alum-formed flocs were broken apart by turbulence prior to entering the flotation tank. Jar tests were conducted with a high alum dosage. Better flotation was achieved but the subnatant was cloudier. It was decided to discontinue alum addition and polymer addition.

The system was operated for 1 additional wk without chemicals, then the sampling program was temporarily suspended at the end of January 1981. Additional modifications were made to the pilot plant to improve removal of screenings and rags encountered in the first raw wastewater phase of the project. The influent channel was widened and more bar racks (approximately five times the original racks' cross-sectional area) were installed as well as a baffle to reduce the approach velocity to the racks. The pilot plant influent line was switched to the grit chamber to initiate the second raw wastewater phase of the project. The operators were instructed to clean the bar racks as often as necessary to prevent any rag accumulations from overflowing the racks and entering the Deep Shaft system.

Second Raw Wastewater Phase

The second raw wastewater phase lasted from February to August 1981 and was comprised of two operating periods divided by a shutdown period. The pilot plant operated primarily on a diurnal flow pattern without polymer addition during both operating periods. On April 10, the plant was temporarily shut down as scheduled for the anticipated bypass season at the main plant. Initially, polymer was added to the system to establish a good float blanket and then discontinued after a few days. During the second raw wastewater phase, no recurrence of the excessive foaming situation that developed during the first raw wastewater phase was observed. In the first operating period of the second raw wastewater phase, the process was disrupted several times as a result of operations at the main plant, including bypassing on several days and failure of the operators to switch the pilot plant to primary effluent while draining the sludge holding tank. Without polymer addition, the float blanket became quite thin and virtually nonexistent. Sink solids were the primary source of waste sludge, and the sink recycle and wasting rates were the primary means of controlling the MLSS level in the shaft. During late February and March, the system appeared to be malfunctioning as high liquid levels were observed in the head tank and holding tank, the cause of which could not be pinpointed. It was concluded that the R_2 section of the shaft might be partially blocked.

On March 20, the shaft was deliberately reversed to dislodge any partial blockages, during which time the flotation tank feed pots were inspected and found to contain a large accumulation of sludge solids mixed with fibrous material. The flotation tank was drained and the internal piping disassembled for cleaning. The R_2 section out of the shaft was also disassembled and flushed out by turning the influent pumps on. Heavy accumulations of sludge solids and fibrous materials including large rags spilled out of R_2. Upon restarting the shaft, the high head tank and holding tank levels were eliminated and the system returned to normal. Thereafter, a noticeable improvement in the float blanket and effluent quality was observed until the plant was shutdown on April 10 for the bypass season.

On May 18, 1981, pilot plant operation was resumed under Eco Technology supervision. The sampling program was restarted June 1 and continued through the end of August when the experimental program was completed. During this time period, the pilot plant continued to operate on diurnal raw wastewater flow without polymer addition. Phosphorus supplementation was provided at various times as Eco Technology personnel were concerned about the possibility of a phosphorus limitation. Some minor mechanical problems were encountered during this time period, but generally the plant operated in a routine fashion with no unusual occurrences. The pilot plant did receive some unusually heavy solids loadings from the digester operations at the main plant that probably adversely affected process performance. Nevertheless, the system performed consistently well during this 3-mo period.

OPERATING RESULTS

Operational Characteristics

Complete summaries of the pilot plant operational characteristics are given in Tables 5 and 6. Hydraulic characteristics including influent flow rate, peaking factor, HRT, and flotation tank surface overflow rate are summarized in Table 5. Operational data including influent temperature, chemical dosage, volumetric organic loading, MLSS concentration, F/M loading, and solids retention time (SRT) are presented in Table 6. The experimental results are tabulated by phases and modes of operation rather than chronologically to facilitate comparisons under various operating conditions. The tables are divided into two phases of operation: raw wastewater and primary effluent. Each phase of operation is subdivided into two

TABLE 5. PILOT PLANT HYDRAULIC CHARACTERISTICS

Operating Mode (Dates)	Influent Flow Rate		Bioreactor* HRT(min)	Solids Separation Unit*	
	m^3/day (gpd)	Peak/Avg.		HRT (hr)	Overflow Rate $m^3/day/m^2$ (gpd/ft^2)
Raw Wastewater					
Constant flow - N.P.					
06/10/80-07/10/80	681 (180,000)	1.0	50	5.2	18.1 (444)
Constant flow - W.P.					
05/19/80-06/09/80	703 (186,000)	1.0	48	5.1	18.7 (459)
Diurnal flow - N.P.					
07/14/80-07/31/80	708 (187,000)	1.6	48	5.1	18.8 (462)
08/01/80-08/31/80	708 (187,000)	1.6	48	5.1	18.8 (462)
09/01/80-09/31/80	711 (188,000)	1.6	48	5.0	18.9 (464)
10/01/80-10/20/80	714 (189,000)	1.6	47	5.0	19.1 (467)
02/19/81-02/28/81	753 (199,000)	1.4	45	4.7	20.0 (491)
03/01/81-03/31/80	726 (192,000)	1.4	47	4.9	19.3 (474)
04/01/81-04/10/81	723 (191,000)	1.4	47	4.9	19.3 (472)
05/31/81-06/30/81	652 (173,000)	1.4	52	5.5	17.4 (427)
07/01/81-07/31/81	738 (195,000)	1.4	46	4.8	19.6 (481)
08/01/81-08/28/81	636 (168,000)	1.4	53	5.6	16.9 (415)
Primary Effluent					
Constant flow - N.P.					
11/09/80-11/21/80	757 (200,000)	1.0	45	4.7	20.1 (494)
Diurnal flow - N.P.					
12/07/80-12/12/80	703 (186,000)	1.4	48	5.1	18.7 (459)
01/24/81-01/30-81	737 (195,000)	1.4	46	4.8	19.6 (481)
Diurnal flow - W.P.					
12/14/80-01/12/81	745 (197,000)	1.4	45	4.8	19.8 (486)
Diurnal flow - W.A.					
01/13/81-01/23/81	745 (197,000)	1.4	45	4.8	19.8 (486)

*Based on influent flow N.P. = no polymer W.P. = with polymer W.A. = with alum

TABLE 6. PILOT PLANT OPERATIONS DATA SUMMARY

Operating Mode (Dates)	Inf. Temp. (°C)	Chem. Dose (mg/l)	Vol. Org. Loading*	MLSS (mg/l)	MLSS (% Vol.)	F/M Loading**	SRT (days)
Raw Wastewater							
Constant flow - N.P.							
06/10/80-07/10/80	19-23	--	3.3 (205)	5,700	67	0.93	1.9
Constant flow - W.P.							
05/19/80-06/09/80	16-20	1.5-2.8	2.5 (154)	5,210	69	0.88	1.0
Diurnal flow - N.P.							
07/14/80-07/31/80	24-25	--	2.8 (174)	7,817	64	0.91	1.4
08/01/80-08/31/80	23-25	--	2.8 (173)	6,408	64	0.68	1.9
09/01/80-09/30/80	23-25	--	3.9 (245)	8,633	67	0.75	2.2
10/01/80-10/20/80	21-23	--	4.4 (275)	6,931	70	1.00	1.6
02/19/81-02/28/81	11-14	--	3.3 (204)	5,700	72	0.77	--
03/01/81-03/31/81	11-13	--	4.9 (304)	6,908	75	0.95	1.9
04/01/81-04/10/81	11-16	--	4.4 (270)	7,151	75	0.79	--
05/31/81-06/30/81	19-22	--	2.5 (159)	8,261	63	0.52	3.7
07/01/81-07/31/81	22-25	--	3.7 (233)	7,772	69	0.54	3.3
08/01/81-08/28/81	24-25	--	2.6 (164)	9,771	59	0.51	2.5
Primary Effluent							
Constant flow - N.P.							
11/09/80-11/21/80	15-19	--	3.4 (214)	6,520	72	0.88	2.6
Diurnal flow - N.P.							
12/07/80-12/12/80	14-15	--	3.5 (221)	7,260	70	0.76	--
01/24/81-01/30/81	14-15	--	3.4 (215)	6,757	68	--	--
Diurnal flow - W.P.							
12/14/80-01/12/81	9-17	0.5-3.0	2.2 (137)	5,720	71	0.58	4.0
Diurnal flow - W.A.							
01/13/81-01/23/81	13-15	40.0	2.2 (137)	6,403	68	0.55	--

* kg BOD_5/day/m^3 (lb BOD_5/day/1,000 ft^3) ** kg BOD_5/day/kg MLVSS

modes of operation: constant flow and diurnal flow, each with and without chemical addition. Polymer was added at various times as a flotation aid and during one period to control foaming. Alum was added for phosphorus removal for a short time period in which alum addition was evaluated with and without polymer as a flotation aid.

The average influent flow rate varied between 636 m^3/d (168,000 gpd) and 757 m^3/d (200,000 gpd) as shown in Table 5. The design flow was 757 m^3/d (200,000 gpd). The sustained peaking factor for the diurnal flow periods ranged from 1.4 to 1.6. The bioreactor HRT is based on the volume of the shaft and head tank and the influent flow rate exclusive of recycle flows back to the shaft. The flotation tank HRT and surface overflow rates are also based upon the influent flow rate exclusive of recycle flows. As indicated in Table 6, the volumetric organic loading ranged from 2.2 to 4.9 kg $BOD_5/day/m^3$ (137 to 304 $lb/day/1000\ ft^3$), the MLSS level from 5,200 mg/l to 9,800 mg/l, and the F/M loading from 0.51 to 1.0 kg BOD_5/day/kg MLVSS. The SRT varied from 1.0 to 4.0 days based on shaft and head tank solids only. It was not possible to accurately estimate the solids in the flotation tank to calculate SRT values based on total solids inventory.

Only a limited amount of cold weather operational data could be obtained, and most of that was obtained while treating primary effluent. Influent wastewater temperatures ranged from 9 to 25°C. The pilot plant was shut down for modifications during the first of two winter seasons occurring during the experimental program. A number of operational problems were encountered during the only cold weather period while treating raw wastewater.

BOD_5, COD, and Suspended Solids Removals

Summaries of BOD_5, COD, and suspended solids data are given in Tables 7, 8, and 9, respectively, for all operating periods. A complete summary of all duplicate analyses that were performed at various times during the course of the study is presented in Table 10. Selected duplicate analyses were performed at the Ithaca plant laboratory for a portion of the study period, and during the last 3 mo of the evaluation phase, duplicate analyses as well as additional analyses were performed in the Eco Technology Mobile Laboratory. All daily analytical data reported by the three participating laboratories is contained in the Appendices. Analytical data for other parameters, including phosphorus, volatile suspended solids, nitrogen series, etc., have not been summarized since they are not the primary indicators of process performance, but are contained in the Appendices.

TABLE 7. PILOT PLANT BOD$_5$ DATA SUMMARY

Operating Mode (Dates)	Days Sampled	Influent (mg/l) Mean	Influent (mg/l) S.D.	Influent (mg/l) Range	Effluent (mg/l) Mean	Effluent (mg/l) S.D.	Effluent (mg/l) Range	% Removal Mean	% Removal S.D.	% Removal Range
Raw Wastewater										
Constant flow - N.P.										
06/10/80-07/10/80	20	102	41	41-175	17	7	9-29	81	11	60-94
Constant flow - W.P.										
05/19/80-06/09/80	15	76	44	35-179	18	7	7-30	67	24	17-95
Diurnal flow - N.P.										
07/14/80-07/31/80	13	84	32	36-138	26	11	13-45	64	21	19-88
08/01/80-08/31/80	19	90	28	45-143	33	16	14-66	64	20	0-87
09/01/80-09/31/80	15	128	44	58-198	37	16	16-72	69	13	46-90
10/01/80-10/20/80	13	145	44	76-222	37	15	22-68	73	13	34-85
02/19/81-02/28/81	5	106	34	73-148	26	10	15-40	73	13	55-90
03/01/81-03/31/81	17	154	36	84-248	34	21	17-98	78	11	49-90
04/01/81-04/10/81	7	137	41	86-209	17	2	15-21	87	4	81-93
05/31/81-06/30/81	23	89	25	36-136	19	9	6-35	74	18	17-95
07/01/81-07/31/81	19	116	30	73-156	25	6	14-38	77	8	59-90
08/01/81-08/28/81	20	114	46	64-236	23	9	9-43	76	9	58-91
Primary Effluent										
Constant flow - N.P.										
11/09/80-11/21/80	10	105	33	76-190	32	10	18-49	67	12	51-90
Diurnal flow - N.P.										
12/07/80-12/12/80	5	118	74	75-247	40	14	29-40	62	10	47-74
01/24/81-01/30-81	4	112	33	71-150	33	1	32-34	69	10	55-79
Diurnal flow - W.P.										
12/14/80-01/12/81	21	71	23	36-115	32	16	9-70	55	17	17-82
Diurnal flow - W.A.										
01/13/81-01/23/81	8	70	13	54-92	21	6	13-33	69	12	48-81

S.D. = standard deviation N.P. = no polymer W.P. = with polymer W.A. = with alum

TABLE 8. PILOT PLANT COD DATA SUMMARY

Operating Mode (Dates)	Days Sampled	Influent (mg/l)			Effluent (mg/l)			% Removal		
		Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range
Raw Wastewater										
Constant flow - N.P. 06/10/80-07/10/80	20	276	98	122-473	50	26	26-119	80	9	59-92
Constant flow - W.P. 05/19/80-06/09/80	15	240	144	54-501	81	44	34-155	58	23	15-93
Diurnal flow - N.P.										
07/14/80-07/31/80	13	313	207	98-882	78	19	53-115	62	25	18-91
08/01/80-08/31/80	20	270	116	107-630	77	31	17-147	65	22	8-94
09/01/80-09/31/80	15	410	137	249-650	81	35	45-162	81	7	69-90
10/01/80-10/20/80	13	379	149	181-666	82	42	24-155	78	13	41-88
02/19/81-02/28/81	5	211	31	186-262	70	25	52-104	67	10	52-77
03/01/81-03/31/81	17	359	77	245-530	90	21	68-146	74	6	60-83
04/01/81-04/10/81	7	331	96	242-526	64	9	47-73	79	7	71-89
05/31/81-06/30/81	23	248	68	135-371	54	8	39-64	77	6	67-86
07/01/81-07/31/81	6	255	45	167-296	40	2	38-43	83	4	77-86
Primary Effluent										
Constant flow - N.P. 11/09/80-11/21/80	10	242	55	192-357	57	21	34-108	76	10	49-85
Diurnal flow - N.P.										
12/07/80-12/12/80	5	266	88	198-421	77	17	58-102	70	7	58-76
01/24/81-01/30/81	4	304	139	163-488	84	24	63-115	69	14	53-81
Diurnal flow - W.P. 12/14/80-01/12/81	21	179	49	100-264	53	22	23-111	72	11	50-96
Diurnal flow - W.A. 01/13/81-01/23/81	8	181	38	146-247	50	20	28-95	72	11	49-83

S.D. = standard deviation N.P. = no polymer W.P. = with polymer W.A. = with alum

TABLE 9. PILOT PLANT SUSPENDED SOLIDS DATA SUMMARY

Operating Mode (Dates)	Days Sampled	Influent (mg/l)			Effluent (mg/l)			% Removal		
		Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range
Raw Wastewater										
Constant flow - N.P.										
06/10/80-07/10/80	20	187	92	68-413	18	12	1-44	89	7	76-99
Constant flow - W.P.										
05/19/80-06/09/80	15	164	135	67-410	25	25	2-92	76	24	6-98
Diurnal flow - N.P.										
07/14/80-07/31/80	13	270	172	90-730	38	18	17-69	80	17	38-95
08/01/80-08/31/80	20	169	77	42-310	41	19	14-90	73	14	33-91
09/01/80-09/31/80	15	376	187	120-632	64	36	3-140	81	7	69-90
10/01/80-10/20/80	13	359	175	88-646	75	51	11-192	78	13	41-88
02/19/81-02/28/81	5	166	46	106-210	49	13	34-70	69	11	54-84
03/01/81-03/31/81	17	231	67	108-344	50	18	20-88	76	10	57-92
04/01/81-04/10/81	7	207	149	96-533	28	13	19-53	84	7	73-92
05/31/81-06/30/81	23	195	82	41-362	29	22	5-91	82	15	25-98
07/01/81-07/31/81	21	246	102	115-465	28	15	8-59	87	8	69-97
08/01/81-08/28/81	19	377	311	129-1320	36	16	7-85	85	6	77-96
Primary Effluent										
Constant flow - N.P.										
11/09/80-11/21/80	10	159	58	84-260	46	29	26-124	69	15	43-90
Diurnal flow - N.P.										
12/07/80-12/12/80	5	144	102	86-325	46	35	19-106	68	8	58-78
01/24/81-01/30/81	4	171	55	106-228	32	18	13-50	78	19	53-94
Diurnal flow - W.P.										
12/14/80-01/12/81	21	98	34	41-156	35	26	6-123	67	16	18-90
Diurnal flow - W.A.										
01/13/81-01/23/81	8	69	26	27-107	14	6	9-23	74	21	37-94

S.D. = standard deviation N.P. = no polymer W.P. = with polymer W.A. = with alum

TABLE 10. PILOT PLANT DUPLICATE ANALYTICAL DATA SUMMARY

Operating Mode (Dates)	Days Sampled	BOD_5 (mg/l) Inf.	BOD_5 (mg/l) Eff.	BOD_5 (mg/l) % Red.	COD (mg/l) Inf.	COD (mg/l) Eff.	COD (mg/l) % Red.	SS (mg/l) Inf.	SS (mg/l) Eff.	SS (mg/l) % Red.
Raw Wastewater										
Constant flow - N.P.										
06/10/80-07/10/80	--	--	--	--	--	--	--	--	--	--
Constant flow - W.P.										
05/19/80-06/09/80	--	--	--	--	--	--	--	--	--	--
Diurnal flow - N.P.										
07/14/80-07/31/80	--	--	--	--						
08/01/80-08/31/80	7/19	105	37	63	--	--	--	--	--	--
09/01/80-09/31/80	15	160	37	70	--	--	--	--	29	--
10/01/80-10/20/80	12	208	41	80	--	--	--	--	53	--
02/19/81-02/28/81	5	97	31	68	--	--	--	--	52	--
03/01/81-03/31/81	14	139	43	69	--	--	--	112	32	74
04/01/81-04/10/81	6	148	30	77	--	--	--	216	45	78
05/31/81-06/30/81*	30	92	17	79	256	62	73	210	35	79
07/01/81-07/31/81*	31	139	23	83	366	46	86	111	27	81
08/01/81-08/28/81*	25	130	19	84	390	51	85	230	24	87
								324	30	88
Primary Effluent										
Constant flow - N.P.										
11/09/80-11/21/80	9	135	40	70	--	--	--	156	43	72
Diurnal flow - N.P.										
12/07/80-12/12/80	5	276	62	78	--	--	--	168	34	80
01/24/81-01/30/81	4	105	15	86	--	--	--	171	49	71
Diurnal flow - W.P.										
12/14/80-01/12/81	21	143	51	64	--	--	--	109	28	65
Diurnal flow - W.A.										
01/13/81-01/23/81	7	99	39	61	--	--	--	109	27	75

*Analyses performed by Eco-Technology Mobile Laboratory; all others performed by Ithaca STP Laboratory
N.P. = no polymer W.P. = with polymer W.A. = with alum

All of the data gathered during various operating phases and modes are presented; however, because of the numerous mechanical breakdowns, excessive foaming, shaft partial blockages, disruptions, operations at the main plant, etc., occurring throughout much of the study as previously outlined, there were only a few time periods when a normal, routine operation was established. Therefore, much of the data collected cannot be considered to be representative or typical of Deep Shaft process performance. A routine or close-to-routine operation was established only during the following time periods:

May 19 - July 10, 1980
April 1 - April 10, 1981
May 31 - August 28, 1981

The following results obtained during these time frames were considered to be more representative of process performance and Deep Shaft capability and, therefore, were focused on for evaluation purposes. Percent reductions represent removals across the pilot system only and do not account for any removals occurring in the main plant's degritting unit:

	BOD_5 (mg/l)			COD (mg/l)			SS (mg/l)		
Period	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.	Inf.	Eff.	% Red.
5/19 - 7/10/80	91	17	80	261	63	76	172	21	88
4/01 - 4/10/81	137	17	88	331	64	81	207	28	86
5/31 - 8/28/81*	105	22	79	250	52	79	267	31	88

*Effluent BOD_5 results may reflect some nitrogenous oxygen demand; nitrification inhibitors were not utilized in the BOD_5 analysis although partial nitrification did occur in the system during a portion of this time period.

Good removals were obtained during these periods, while inconsistent and erratic results were often obtained during those periods when operational problems were encountered. Effluent soluble BOD_5 values, however, were consistently below 10 mg/l during all periods of operation, indicating that biological oxidation occurred under all conditions of operation, adverse and otherwise. This would seem to indicate that the solids separation unit was more subject to upset than the biological process.

Influent BOD_5 concentrations were extremely low throughout the entire course of the study because of large quantities of infiltration/inflow entering the collection system. Volumetric organic loadings to the pilot plant were lower than anticipated because of the weak nature of the City's wastewater. Influent suspended solids concentrations were high, relative to the BOD_5 concentration, and extremely variable, especially during the raw wastewater phase as indicated by the large standard deviation in Table 9. The high suspended solids concentrations as well as the large variations reflect primarily the impact of digester operations and "dump" periods at the main plant.

Time plots of influent and effluent BOD_5, COD, and suspended solids for the period May 31, 1981, to August 28, 1981, are presented in Figures 6, 7, and 8, respectively. Effluent soluble BOD_5 and COD data, although limited in this period, are shown as well as total BOD_5 and COD data. COD analyses by the commercial laboratory were discontinued in early July; however, the Eco Technology Mobile Laboratory continued to run COD analyses. The plots illustrate the large variability in influent concentrations for all three parameters. Relatively consistent effluent BOD_5 and suspended solids concentrations were achieved. Effluent COD results were somewhat variable. This 3-mo period represents the longest duration that a routine operation was established, and the data obtained therein are considered the most useful in terms of evaluating Deep Shaft process performance and operational characteristics.

Comparisons of process performance and operational characteristics between various phases or modes of operation, such as raw wastewater versus primary effluent, polymer versus no polymer, diurnal versus constant flow, temperature variations, and alum addition, are difficult because of the other numerous uncontrollable variables encountered during much of the study period that also affected process performance. All data should be examined in light of these other variables and their potential adverse effects.

Phosphorus Removal

A summary of phosphorus removal data obtained during the alum addition phase of the study is contained in Table 11. It can be seen that relatively good removals of phosphorus were obtained during this period. However, as previously discussed, alum addition with or without polymer addition appeared to have a negative impact on the process as the float blanket became very thin and most solids were sinking. Because of this effect, the alum addition phase of the study was curtailed. Phosphorus analyses were periodically performed throughout the course of the study to determine any possibility of a nutrient limitation and to provide information on phosphorus uptake by the biota. Influent orthophosphorus concentrations at times were found to be quite low, and phosphorus supplementation was provided twice during the study to ensure that a phosphorus deficiency did not exist. Ferric chloride is used at the main plant for sludge conditioning prior to vacuum filtration. It was theorized that the return of filtrate during dewatering operations could tie up available phosphorus in the pilot plant influent causing a phosphorus limitation. Phosphorus supplementation did not appear to

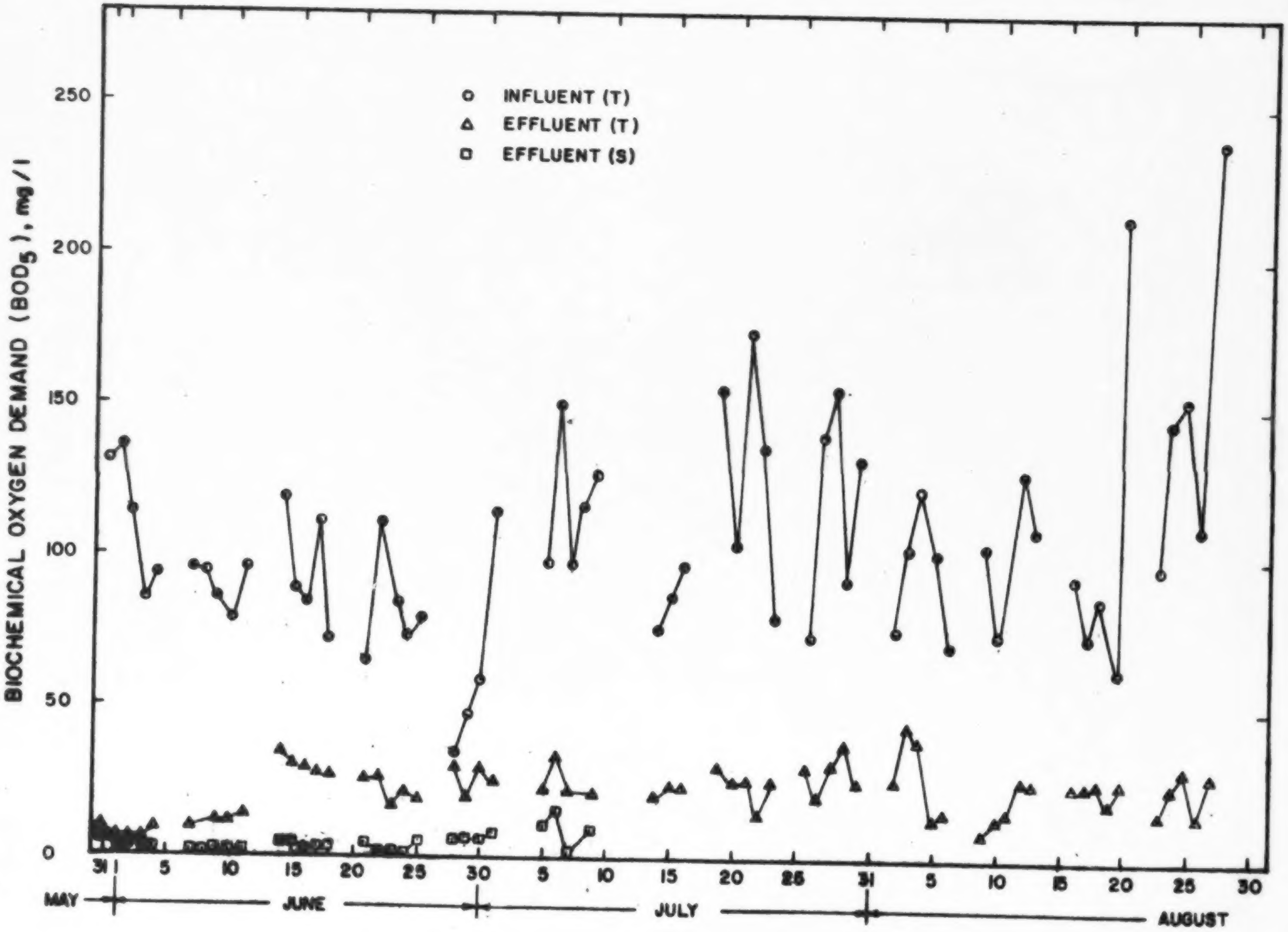


Figure 6. Total and soluble BOD$_5$ results from May 31 to August 27, 1981.

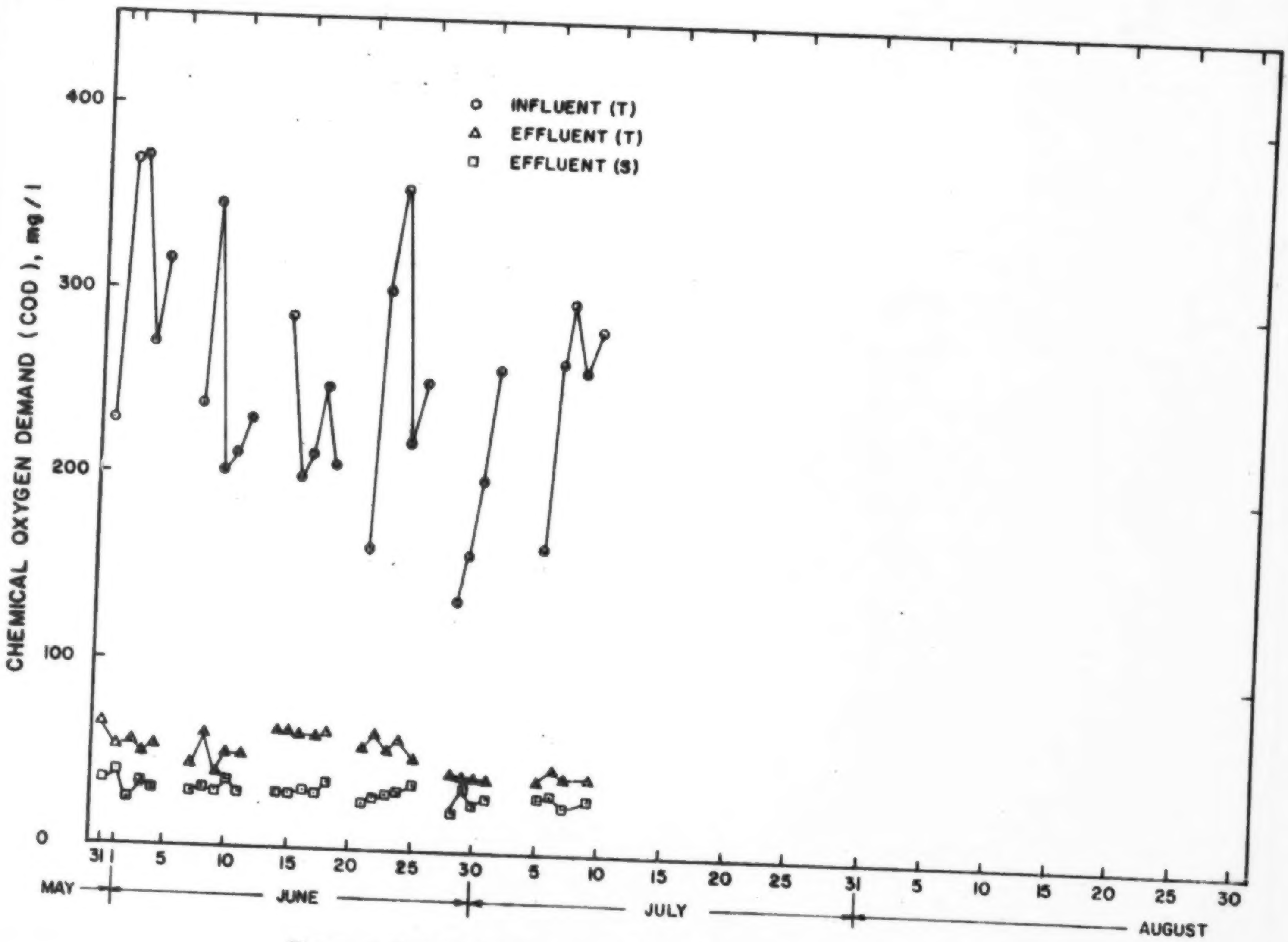


Figure 7. Total and soluble COD results from May 31 to JULY 9, 1981.

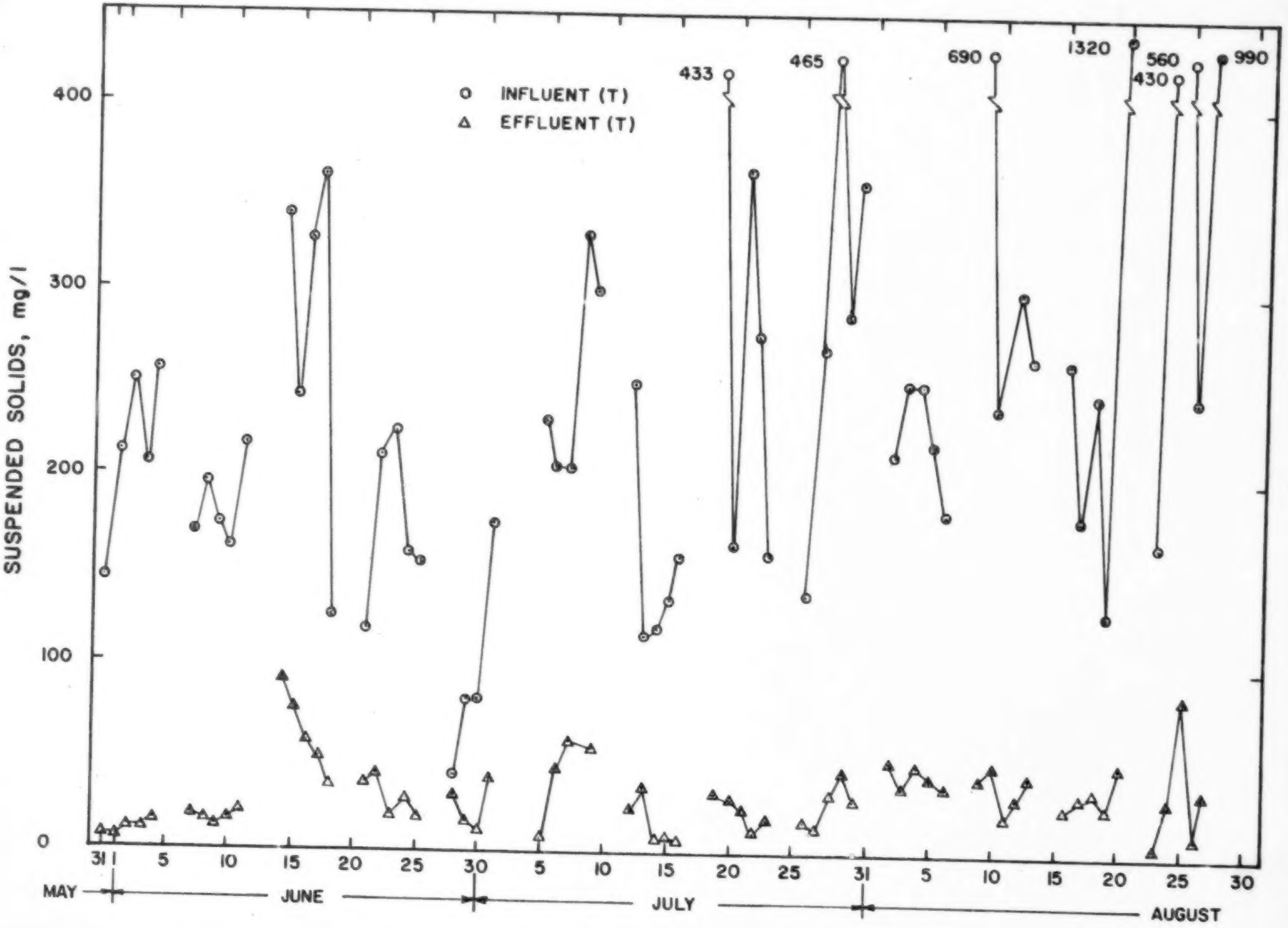


Figure 8. Suspended solids results from May 31 to August 27, 1981.

have a significant impact on process performance and it was discontinued.

Sludge Production

Sludge characteristics and production were monitored throughout the study and are summarized in Tables 12 and 13. Solids concentrations of float recycle and sink recycle streams, which were randomly determined by plant operators and by Eco Technology Mobile Laboratory personnel when on-site, are given in Table 12. The solids concentrations varied from 2.7 to 4.7 percent in the float recycle stream and from 1.0 to 2.5 percent in the sink recycle stream.

Waste sludge concentrations and sludge production data are presented in Table 13. Sludge was wasted to a sludge measurement tank from the flotation tank beach and the sink recycle line. The volume of each tankful of sludge wasted was recorded, and a sample was collected for solids analysis. As indicated in Table 13, the concentration of float solids wasted varied from 1.6 to 4.8 percent. Waste sink solids concentrations varied from 1.5 to 2.4 percent. The solids concentration ranges for float recycle and waste streams differ somewhat since samples were taken at different times and locations. The number of float waste samples taken was much greater than the number of float recycle samples taken. The same was true for the sink recycle and waste streams.

Sludge production rates, based on total and volatile suspended solids, were calculated as a function of both BOD_5 removal and suspended solids removal. A large variation in the relative proportion of sludge wasting requirements from the float and sink recycle streams is evident. Sludge wasting requirements were based primarily on the operator's judgement after observing the float blanket length and thickness, the results of flotation and settling jar tests, and the previous MLSS analysis. Operators were instructed to waste sludge from the float recycle stream whenever possible as the preferred method for controlling the solids inventory. Sludge production calculations do not include those solids lost in the effluent. Sludge production calculations also do not include any type of correction factor for the large volume of digested solids, partially digested solids, and inert solids received at the pilot plant from digester operations at the main plant. Some of the shorter time periods have been eliminated from the table as insufficient data were collected to yield meaningful results.

TABLE 11. PHOSPHORUS REMOVAL WITH ALUM ADDITION*

Date	Phosphorus Concentrations (mg/l)			
	Influent		Effluent	
	Ortho-P	Total-P	Ortho-P	Total-P
1/13/81	3.40	4.06	0.64	1.26
1/14/81	3.36	4.09	0.26	0.81
1/15/81	3.04	4.06	0.39	0.82
1/18/81	2.80	3.38	0.27	0.66
1/19/81	3.64	4.33	1.01	1.42
1/20/81	3.40	4.23	0.20	0.62
1/21/81	2.90	3.23	0.86	2.15
1/22/81	2.80	3.77	0.27	1.42
Average	3.17	3.89	0.49	1.15

*Alum dosage = 40 mg/l $Al_2(SO_4)_3 \cdot 14H_2O$

TABLE 12. FLOAT AND SINK RECYCLE SOLIDS CONCENTRATIONS

Operating Modes (Dates)	Suspended Solids			
	Float Recycle		Sink Recycle	
	No. of Samples	mg/l	No. of Samples	mg/l
Raw Wastewater				
Constant flow - N.P. 06/10/80-07/10/80	--	--	18	17,622
Constant flow - W.P. 05/19/80-06/09/80	--	--	9	14,476
Diurnal flow - N.P.				
07/14/80-07/31/80	--	--	6	11,272
08/01/80-08/31/80	13	46,563	23	13,688
09/01/80-09/30/80	3	36,187	6	24,287
02/19/81-02/28/81	--	--	9	17,241
03/01/81-03/31/81	--	--	23	17,780
04/01/81-04/10/81	--	--	8	22,610
05/31/81-06/30/81	18	34,424	24	21,701
07/01/81-07/31/81	31	26,627	31	22,008
08/01/81-08/28/81	30	32,132	30	25,022
Primary Effluent				
Constant flow - N.P. 11/09/80-11/21/80	--	--	2	18,733
Diurnal flow - W.P. 12/14/80-01/12/81	--	--	8	10,164

N.P. = no polymer W.P. = with polymer

TABLE 13. PILOT PLANT SLUDGE PRODUCTION SUMMARY

Operating Mode (Dates)	Waste Sludge (mg SS/l)		Sludge Production					
			kg SS/day (lb SS/day)					
	Float	Sink	Float	Sink	kg SS/kg BOD_5 Rem.	kg SS/kg SS Rem.	kg VSS/kg BOD_5 Rem.	kg VSS/kg SS Rem.
Raw Wastewater								
Constant flow - N.P.								
06/10/80-07/10/80	41,190	20,140	92 (42)	158 (72)	1.0	0.5	0.7	0.3
Constant flow - W.P.								
05/19/80-06/09/80	36,430	22,710	293 (133)	264 (120)	2.5	1.3	1.7	0.9
Diurnal flow - N.P.								
07/14/80-07/31/80	44,820	20,800	396 (180)	202 (92)	1.9	0.6	1.3	0.4
08/01/80-08/31/80	46,890	22,060	191 (87)	117 (53)	1.5	0.7	1.0	0.5
09/01/80-09/30/80	39,400	21,050	163 (74)	33 (15)	0.9	0.3	0.6	0.2
10/01/80-10/20/80	47,000	15,320	297 (135)	31 (14)	0.9	0.3	0.6	0.2
02/19/81-02/28/81	0	18,740	0	377 (170)	1.1	0.9	0.8	0.7
03/01/81-03/31/81	21,600	18,180	20 (9)	224 (102)	0.9	0.6	0.6	0.4
04/01/81-04/10/81	44,230	21,380	262 (119)	319 (145)	1.2	0.8	0.8	0.5
05/31/81-06/30/81	48,295	23,850	59 (27)	200 (91)	0.8	0.3	0.5	0.2
07/01/81-07/31/81	16,460	20,770	42 (19)	255 (116)	1.0	0.4	0.7	0.3
08/01/81-08/28/81	17,790	21,010	84 (38)	304 (138)	1.4	0.4	0.8	0.3
Primary Effluent								
Constant flow - N.P.								
11/09/80-11/21/80	31,200	23,707	90 (41)	48 (22)	0.5	0.3	0.3	0.2
Diurnal flow - W.P.								
12/14/80-01/12/81	29,690	18,610	174 (79)	18 (8)	1.1	0.8	0.7	0.6

N.P. = no polymer W.P. = with polymer

SECTION 8

DISCUSSION OF RESULTS

TREATMENT EFFICIENCY

In evaluating the performance of the Deep Shaft process and its capability to remove pollutants as measured by key parameters such as BOD_5, COD, and suspended solids, it should be noted that the influent wastewater characteristics at the pilot plant were not typical of domestic raw wastewater or primary effluent as had been anticipated in selecting Ithaca as the site for the demonstration project. This resulted from a combination of factors beyond control, including abundant infiltration/inflow into the City's collection system, recycle streams from digester operations at the main plant, inadequate grinding of screenings at the main plant, trickling filter recirculation flows to the primary settling tanks, and suspected acid waste discharges from a local industry.

Influent wastewater characteristics were highly variable. The organic strength of the wastewater was quite low even with the presence of recycle streams back to the head end of the plant. During several periods, the average influent BOD_5 was less than 100 mg/l and some days it was less than 50 mg/l. BOD_5/COD ratios were less than would be expected for typical domestic wastewater. The ratios were generally in the range of 0.3 to 0.4. This was probably a reflection of recycle streams from sludge processing operations at the main plant. Large increases in COD were measured during digester "dump" periods. Similarly, influent suspended solids concentrations were higher than would be expected relative to BOD_5 concentrations for typical domestic wastewater. Influent BOD_5 did not increase as greatly relative to the increases in COD and suspended solids.

Large increases in suspended solids were observed at the pilot plant during sludge processing operations at the main plant. During digester "dump" periods, the pilot plant received a large quantity of digested and partially digested anaerobic solids. These solids were quite odorous and often turned the float blanket in the flotation tank to a dark brown or black color. Although the pilot plant influent was usually switched to primary effluent during dump periods, it took several hours to drain the main plant's sludge holding tank, during which time the primary settling tanks became overloaded and digester solids overflowed the settling tank weirs. Frequently, the sludge holding tank was partially decanted to provide room for pumping additional digested sludge to the holding tank. It was not practical for the operators to switch to primary effluent during all these relatively short time periods. Consequently, this practice often contributed to the solids loading to the pilot plant. Filtrate from sludge dewatering by vacuum filtration was also returned to the head of the plant and contributed solids to the pilot plant. Ferric chloride and lime were used for conditioning digested sludge prior to mechanical dewatering. The return of filtrate containing ferric chloride to the pilot plant influent caused some concern over the possibility of a phosphorus deficiency for the biota if the ferric chloride tied up part or all of the available phosphorus pool.

The return of inadequately ground screenings to the influent stream at the main plant caused severe clogging problems at the pilot plant. Large accumulations of rags and other debris collected in the system until modifications were made to the pilot plant influent channel and screening system. Primary effluent contained an additional recycle stream not contained in the raw wastewater entering the pilot plant. Trickling filter recirculation flows were returned to the discharge end of the grit chamber after the effluent weir, mixed with degritted raw wastewater, and split between the primary settling tanks. Sludge from the final settling tanks was also pumped to the primary settling tanks. These practices combined with draining of the sludge holding tank resulted in higher suspended solids concentrations in the primary effluent than would otherwise have been expected. Suspended solids levels in the primary effluent generally exceeded BOD_5 concentrations.

Periodically, acid dumps from a local industry were suspected to have been received at the pilot plant. It is unknown how severe or frequent these discharges were or if they had any toxic effect on Deep Shaft biology. A review of raw BOD_5 dilution data frequently indicated the possible presence of toxicity. In addition, the industrial discharges contained large quantities of iron, which could also have periodically contributed to low influent phosphorus levels.

Effective removals of BOD_5, COD, and suspended solids were achieved by the Deep Shaft process during periods when a routine operation was established and no major operational or mechanical difficulties were encountered. During those periods when major operational or mechanical difficulties were encountered, process performance was adversely affected. The data indicate that the solids separation unit was more subject to upset than the Deep Shaft biological oxidation process. Effluent soluble BOD_5 levels were consistently below 10 mg/l during all periods and conditions of operation, suggesting that biological oxidation of carbonaceous matter was always achieved. The higher effluent BOD$_5$ levels obtained during some periods, therefore, resulted from particulate BOD$_5$ associated with biological solids lost over the effluent weir of the flotation tank. The effectiveness of the flotation tank in removing solids, of course, is not independent of the biological process and health of the sludge produced from it. The data and visual observations of the float blanket suggest that the biological process was adversely affected by operational and mechanical problems in its ability to produce a good, healthy biological sludge that was readily flotable, although essentially complete biological oxidation was generally achieved.

For the three periods (May 19-July 10, 1980; April 1-April 10, 1981; May 31-August 28, 1981) focused on to evaluate treatment efficiency of the Deep Shaft system itself, the following weighted averages were obtained:

Parameter	System Influent (mg/l)	System Effluent (mg/l)	% Reduction
BOD$_5$	102	20	80
COD	263	59	78
SS	231	27	88

The above data indicate good removals were obtained, but the influent organic strength was quite low, the BOD$_5$/COD ratio was low, and suspended solids concentrations were high relative to the BOD$_5$ concentrations. Cumulative frequency plots of effluent BOD$_5$, COD, and suspended solids are presented in Figures 9, 10, and 11, respectively, for the longest time period highlighted: May 31, 1981 to August 28, 1981. Total and soluble BOD$_5$ and COD, suspended solids, and removal efficiencies are plotted in these figures. Removal efficiencies on Figures 9 and 10 refer to total BOD$_5$ and total COD, respectively. Figure 10 covers the period up to July 10, 1981, when COD analyses were discontinued.

The plots show the frequency with which effluent concentrations and removal efficiencies were below any selected value. For example, effluent BOD$_5$ values below 30 mg/l were obtained 86 percent of the time and 85 percent or greater removal efficiency was achieved 24 percent of the time. Similarly for suspended solids, effluent concentrations less than 30 mg/l were obtained 52 percent of the time and 85 percent or greater removal efficiency was achieved 50 percent of the time.

The following sections discuss process performance under various operating conditions including primary effluent versus raw wastewater, constant versus diurnal flow, polymer addition, and alum addition based on the limited amount of useful data generated.

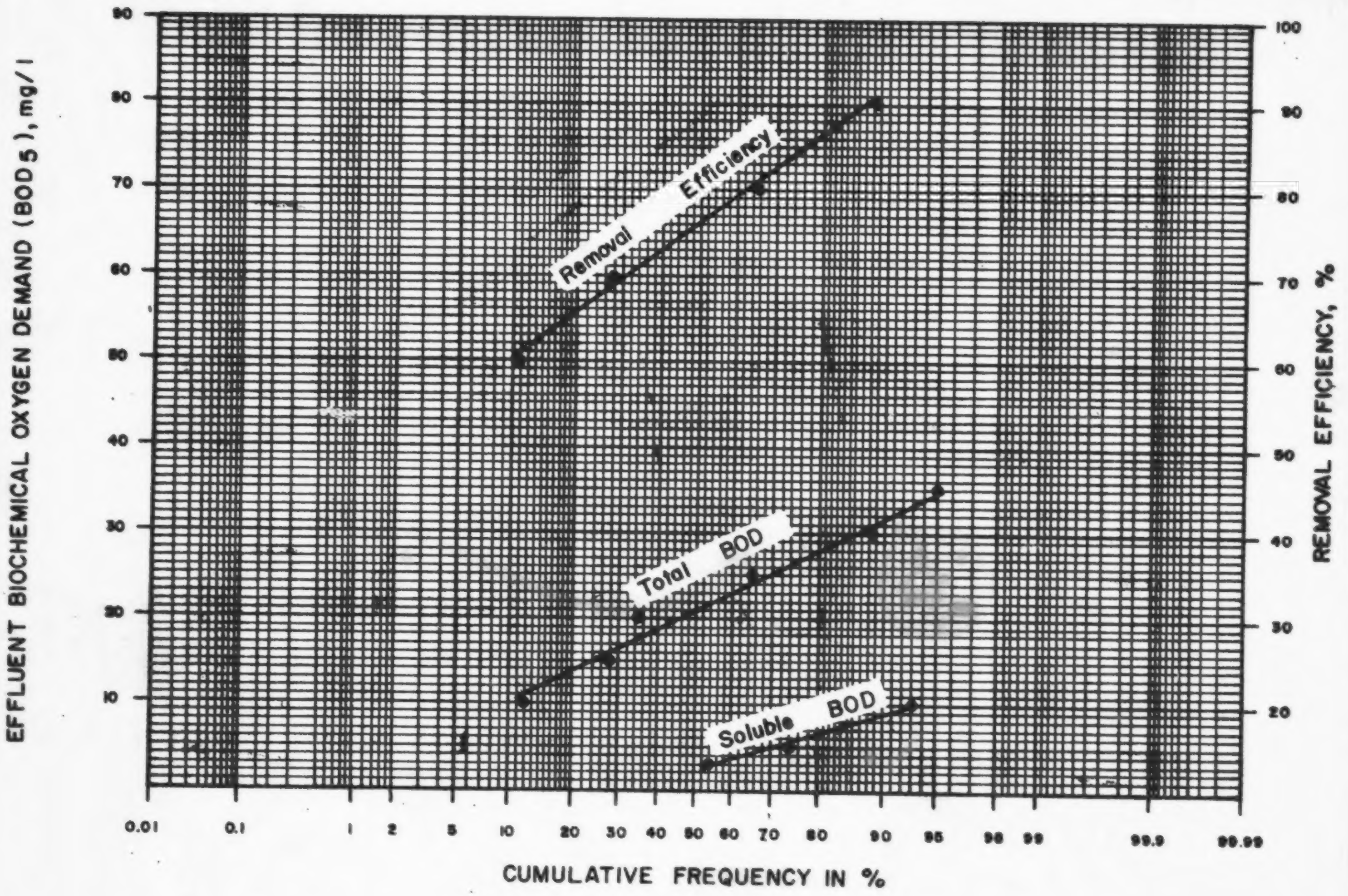


Figure 9. Effluent BOD_5 and removal efficiency frequency distribution, May 31 to August 27, 1981.

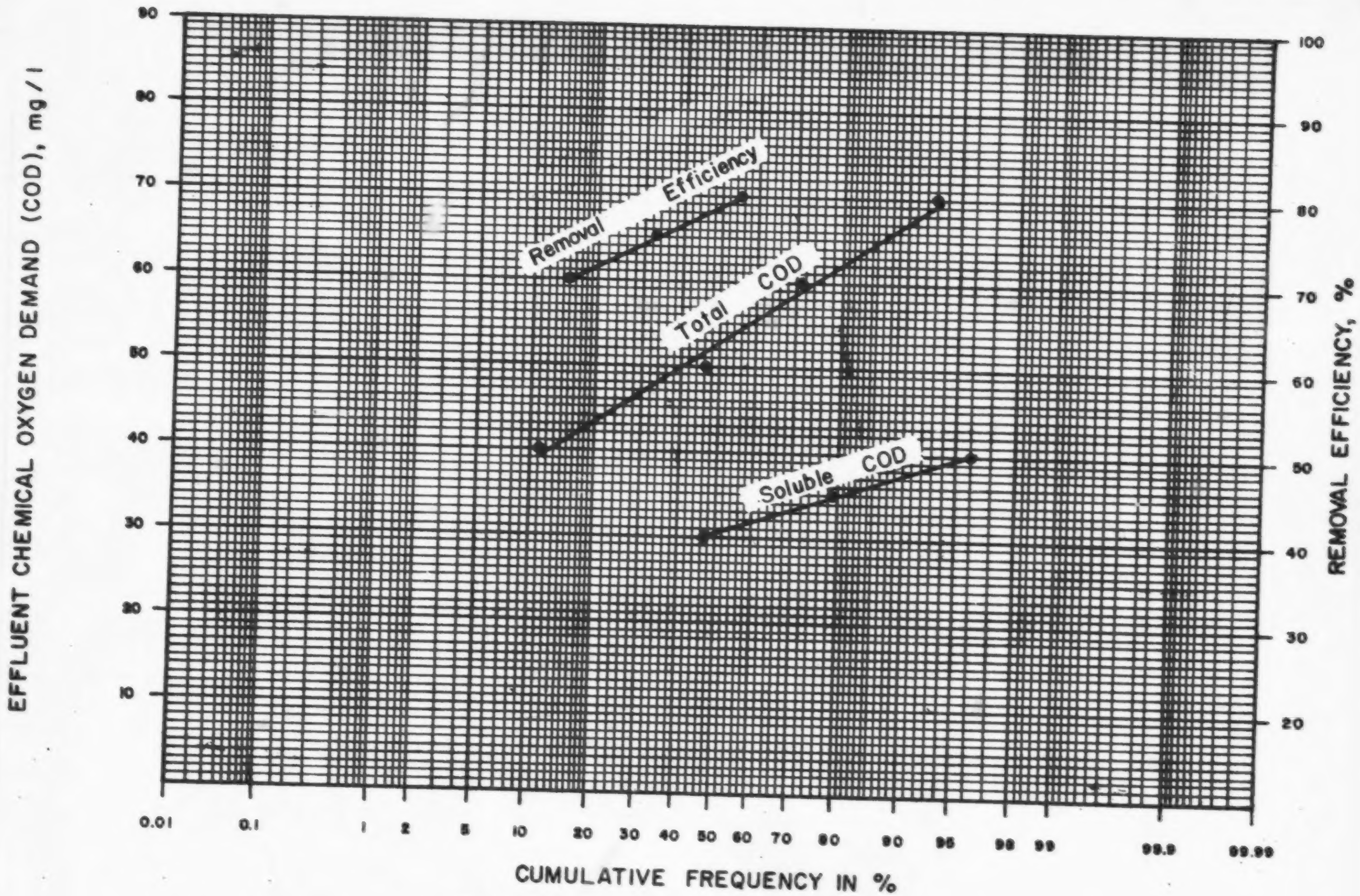


Figure 10. Effluent COD and removal efficiency frequency distribution, May 31 to July 9, 1981.

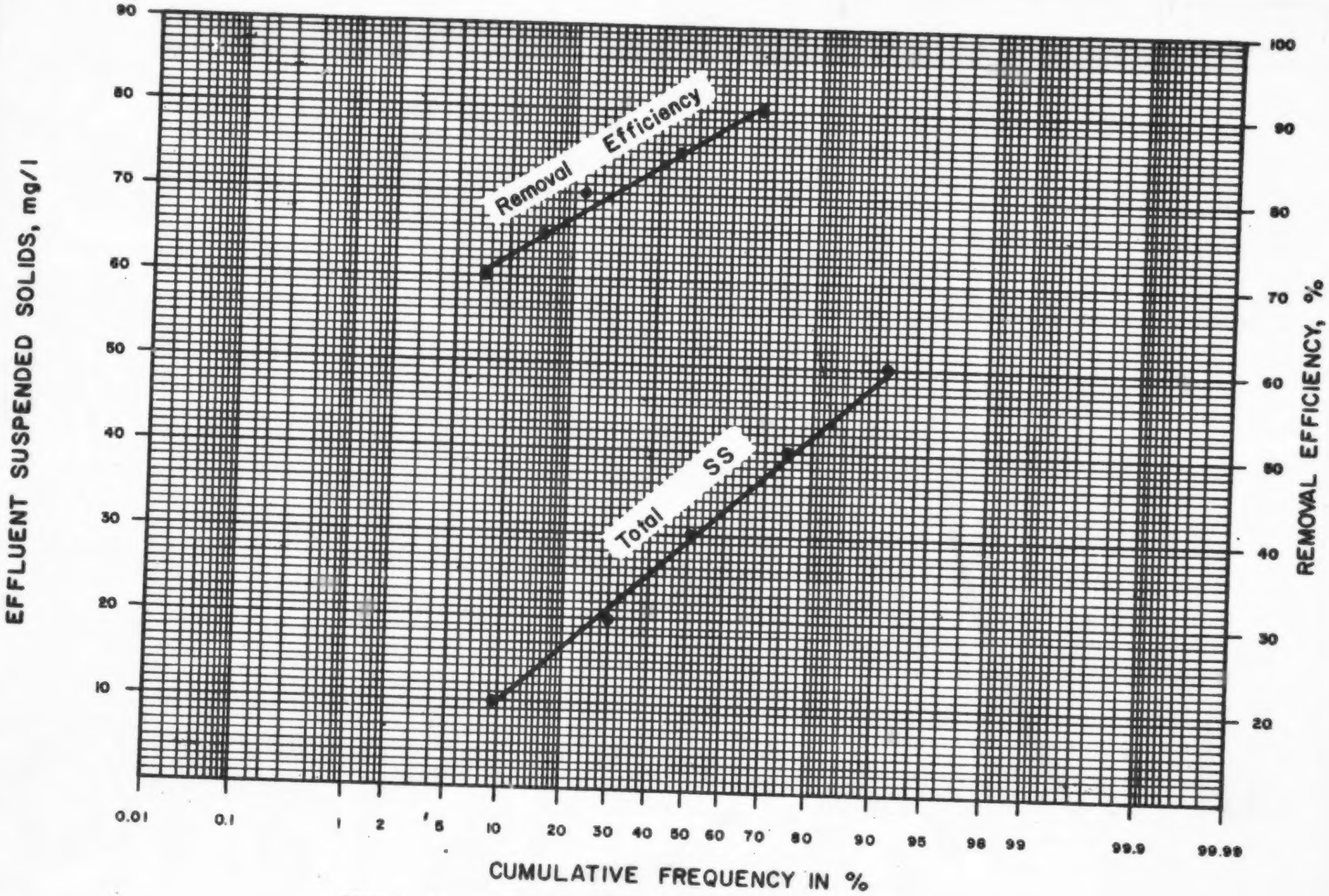


Figure 11. Effluent suspended solids and removal efficiency frequency distribution, May 31 to August 27, 1981.

Primary Effluent Versus Raw Wastewater

It is difficult to compare process performance with primary effluent feed against raw wastewater feed on the basis of the data presented because of the many externally-caused problems encountered while treating primary effluent. However, based on visual appearances, the system was more effective in treating raw wastewater than primary effluent. The float blanket produced while treating primary effluent was very thin and usually dispersed with no distinct endpoint. Consequently, many dispersed solids were carried over the effluent weir. The float blanket produced while treating raw wastewater had a much more healthy appearance, was usually thick, and often had a distinct endpoint. This distinction is probably the result of the lower organic strength associated with primary effluent and the lack of fibrous material. Fibrous material assists in the formation of floc particles that will float more readily. Eco Technology advocates the elimination of primary settling because of these factors and cost considerations. In view of these results and considerations, the primary effluent portion of the study was curtailed as much as possible to focus on process performance treating raw wastewater.

Constant Versus Diurnal Flow

The pilot plant was operated under constant and diurnal influent flow variations on both raw wastewater and primary effluent feed. The system operated more efficiently under a constant flow pattern than a diurnal flow variation. Flow variations appeared to disrupt the float blanket in the flotation tank. Biologically, there did not appear to be any disruption to the process as effluent soluble BOD_5 concentrations remained very low. Sometimes, under diurnal flow conditions, the float blanket would thicken during the morning, start to disperse by mid-afternoon, completely disappear at night, and reappear the following morning. This pattern may have resulted from the large variation in BOD_5 loadings experienced throughout the course of a typical day. BOD_5 loadings were higher during the daytime period when the influent flow was at its maximum sustained peak; conversely, BOD_5 loadings were probably low at night, except during digester dump periods, when the influent flow rate was at its minimum sustained level. Consequently, the BOD_5 loading at night may not have been sufficient to generate a good, thick float blanket. The impact of this situation was the loss of dispersed float solids over the effluent weir at night causing a deterioration of effluent quality. Visually, the effluent often appeared better during the day than the 24-hr composite samples. Discrete samples taken over a 24-hr period on several occasions indicated a worsening of effluent quality at the low load condition. With experience, the float blanket was found to be more controllable by establishing a better sludge wasting schedule.

Polymer Addition

Polymer addition as a flotation aid was tested at various times under different operating conditions to provide a comparison with process performance without polymer addition. The main goal was to operate the system without polymer since polymer addition would represent a significant operating cost in a full-scale application. The data do not indicate any improvement in effluent quality with polymer addition. As would be expected, however, a marked improvement in the volume of float blanket produced was noted. No increase in float blanket solids concentration was observed with polymer addition, but the quantity of float solids produced relative to the quantity of sink solids produced increased substantially. As shown previously in Table 13, the rate of float solids wasting relative to the rate of sink solids wasting increased with polymer addition. At times, it appeared that effluent quality deteriorated somewhat with polymer addition. For example, in the raw wastewater constant flow period, the effluent suspended solids averaged 18 mg/l or 89 percent removal without polymer addition and 25 mg/l or 76 percent removal with polymer addition. This is probably the result of polymer addition causing a number of sink solids to float. Apparently, some of these solids were not sufficiently buoyant to reach the float blanket and were suspended between the float blanket and the sink blanket and eventually carried over the effluent weir.

Polymer addition, in general, was not required to develop a healthy float blanket or a good quality effluent. However, at times the blanket did become quite thin and dispersed for reasons that were not entirely clear. Contributing factors probably included the following or combinations thereof: colder wastewater temperatures, weak influent strength, lack of fibrous material, digested or partially-digested solids, and process upsets. At a full-scale facility, polymer addition probably would be beneficial on an intermittent or seasonal basis to ensure maintenance of a good, thick, healthy float blanket at all times.

At one point in the experimental program, polymer addition apparently did serve, coincidentally, to control excessive foaming throughout the system. One hypothesis for this observed phenomenon is that the addition of polymer increased the water surface tension, thereby decreasing bubble formation significantly.

Alum Addition

Alum addition for phosphorus removal was tested for a short time to evaluate the effects of alum on the Deep Shaft process. Alum was added with and without polymer as a flotation aid while the pilot plant was treating primary effluent. Although the data depict that good removal efficiencies were obtained with alum for all parameters, it was quite apparent that alum addition had disrupted the process. The float blanket became quite thin and dispersed as most of the solids sank to the bottom of the flotation tank. A thin, milky scum appeared on the surface of the flotation tank. Polymer addition was initiated, but did not significantly improve the situation. Jar tests with alum and various polymer dosages suggested that a thick float blanket could be achieved at high alum dosages, but the subnatant became quite cloudy and had a milky appearance. It was agreed by all parties to discontinue alum addition to allow more time in the experimental program for other modes of operation.

Although more data involving the addition of other chemicals for phosphorus removal and the use of a raw wastewater feed would be required to make any conclusive statements, the results at Ithaca suggest that tertiary facilities may be required at full-scale Deep Shaft applications with a phosphorus removal requirement.

SRT AND F/M AND VOLUMETRIC LOADINGS

The Deep Shaft process was demonstrated to be a high-rate activated sludge process as expected. Average F/M loadings ranged from about 0.5 to 1.0 kg BOD_5/day/kg MLVSS. The original design F/M loading was 0.75 kg BOD_5/day/kg MLVSS. The process operated satisfactorily in this range of F/M loadings and did not appear to be organically or hydraulically overloaded on an average daily basis. The average daily shaft HRT, excluding recycle flows, ranged from 45 to 53 min. There was no evidence of an organic breakthrough at any point in the study. Effluent soluble BOD_5 values were normally below 10 mg/l and often below 5 mg/l throughout the course of the study.

SRT values ranged from 1 to 4 days based on the shaft and head tank solids inventory. The actual SRT including the flotation tank solids inventory would be somewhat longer; however, it was impossible to accurately estimate the solids inventory in the flotation tank. The SRT appeared to be adequate for the range of wastewater temperatures evaluated.

The average volumetric BOD_5 loading was well below the design loading of 5.7 kg BOD_5/day/m^3 (354 lb/day/1000 ft^3), ranging from 2.2 to 4.7 kg BOD_5/day/m^3 (137 to 291 lb/day/1000 ft^3). The lower organic loadings resulted from the lower-than-expected influent BOD_5 concentrations in the City's raw wastewater.

TEMPERATURE EFFECTS

Very little significant data were gathered during cold weather periods to evaluate the effects of temperature on the Deep Shaft process. The pilot plant was not in operation during the 1979-1980 winter season. It was in operation during the 1980-1981 winter season from December 7, 1980, to January 30, 1981, treating primary effluent and from February 19 to March 31, 1981, treating raw wastewater. Wastewater temperatures were in the range of 9 to 17°C during the first period and in the range of 11 to 14°C during the latter period. In general, the pilot plant did not operate particularly well during either of these periods; however, a number of other variables probably affected the process more than wastewater temperature. During these periods, excessive foaming occurred in the system and later there was a partial blockage in R_2. Alum addition was also tested during the first time period. Based on these considerations, the effects of cold wastewater temperature on the process could not be defined.

ORGANIC AND HYDRAULIC SHOCK LOADINGS

The pilot plant was subjected to a number of severe organic shock loadings, sometimes several a week, primarily as a result of digester operations at the main plant. Shock organic loadings consisted of digester supernatant, filtrate from sludge dewatering, and digested and partially digested solids from the sludge holding tank while draining the tank prior to mechanical sludge dewatering. During startup, the pilot plant received the full impact of these recycle streams as the primary effluent piping had not yet been installed. Primary effluent piping was installed later when the pilot plant was shutdown for modifications after the initial startup period. After the primary effluent piping was installed, the influent to the pilot plant was generally switched to primary effluent during the dump periods. Consequently, the startup period provided the best information regarding the effects of shock organic loads on the system.

During the initial 6 wk of plant startup, Eco Technology provided the services of a mobile analytical laboratory at the plant site. Process performance was monitored around the clock by analyzing 2-hr composite samples of influent and effluent for COD and suspended solids. During startup, the pilot plant received large organic loadings twice per week for periods lasting approximately 5 hr. During a typical dump period, the influent suspended solids level increased to 3800 mg/l and the COD concentration increased to 5000 mg/l. Effluent suspended solids rose to 50 mg/l from a value below 30 mg/l, and effluent soluble COD reached a peak of 140 mg/l from a value of 100 mg/l. The process was adversely affected only on a short-term basis and rapidly recovered within 12 to 24 hr following cessation of the dump period. The rapid recovery of the process from these digester dumps with 10- to 20-fold increases in influent suspended solids and COD was demonstrated several times during the startup period (19).

As previously discussed, the pilot plant was operated under a diurnal flow pattern with sustained peak flows to simulate dry-weather conditions at a typical domestic wastewater treatment facility. It was not possible, however, to evaluate the capability of the process to handle large instantaneous or short-term peak flows typically encountered during wet-weather periods at most treatment plants. It was hoped to increase the peak influent flow rate to 2,271 m^3/day (600,000 gpd), or a peaking factor of 3.0 to determine its effect on the process. The design of the Ithaca shaft, however, was such that the total hydraulic capacity including recycle flows was 1,666 m^3/day (440,000 gpd). The maximum influent flow limit was established at approximately 1,060 m^3/day (280,000 gpd). Consequently, the system could not be evaluated under simulated wet-weather flow conditions and the dry-weather peak flow was slightly less than the desired sustained peak of 1,136 m^3/day (300,000 gpd).

SLUDGE PRODUCTION AND THICKENING

The volume of each tankful of sludge wasted from the Deep Shaft system was recorded, and samples of each tankful were analyzed for suspended solids. Volatile suspended solids were analyzed on an intermittent basis. Sludge production values in Table 13 are presented for only those time periods that were sufficiently long to obtain meaningful data. These data indicate that a significant quantity of solids had to be wasted from the sink recycle line as well as the float return to properly control the process. It had been anticipated that the vast majority of solids would float forming a very thick blanket that would be the primary source of sludge wasting and that float recycle would be the primary mechanism for controlling the shaft MLSS level. A large variation was experienced in the relative rates of float and sink solids wasting. At times, the quantity of sink solids wasted exceeded the quantity of float solids wasted; at other times, the opposite was true. This variation was probably a function of the quantity and condition of digester solids received from sludge processing operations at the main plant as well as such factors as polymer addition.

Control of the shaft MLSS level was primarily accomplished by controlling the sink solids inventory. The concentration of float solids was not as high as anticipated, and the float return rate was much less than the sink recycle rate. Float solids concentrations were about 4 percent and sink solids concentrations around 2 percent. The float return rate was estimated to be approximately 76 m^3/day (20,000 gpd), and the sink return rate was always at least 303 m^3/day (80,000 gpd) and often over 379 m3/day (100,000 gpd). Consequently, the process was primarily controlled by the wasting and recycle rates for sink solids. Although this is contrary to the principles and inherent advantages of the Deep Shaft process that are expected by coupling it with a flotation tank, the system was able to operate well. The high sink solids concentration was a result of the high inert solids loading. The flotation clarifier allowed this inert material to be preferentially removed from the Deep Shaft system via the sink recycle line, thereby maintaining a biomass of higher volatile content than would otherwise be possible.

The float blanket solids concentration was not as high as anticipated, and the quantity of sink solids generated relative to float solids was much more than anticipated. The most obvious explanation to these observations is that the large quantity of digested and partially digested anaerobic solids received at the pilot plant were not readily flotable. Deep Shaft biology may have been adversely affected such that polymeric substances produced by the biota that aid in flotation were not secreted to the extent that they are at other Deep Shaft applications devoid of such solids loadings. It would be difficult to predict the expected sludge characteristics for an application involving typical domestic wastewater based on the results obtained at Ithaca.

Sludge production rates in Table 13 were calculated on the bases of BOD_5 and suspended solids removals. The following overall weighted averages were determined on the basis of period duration:

Parameter	Sludge Production	
	Raw Wastewater	Primary Effluent
kg SS/kg BOD_5 removed	1.20	0.92
kg VSS/kg BOD_5 removed	0.81	0.58
kg SS/kg SS removed	0.55	0.65
kg VSS/kg SS removed	0.38	0.48

It can be seen that a large difference exists in waste sludge production values based upon BOD_5 removals between the two phases of operation. Although the period for primary effluent feed is much shorter than that for raw wastewater feed, 0.58 kg VSS/kg BOD_5 removed probably is a more accurate estimate of the actual biological sludge production. In calculating waste sludge production rates, no attempt was made to correct for that quantity of organic solids that may have settled out of the system without being oxidized. These solids would generally be removed in primary settling tanks and, therefore, have less impact on sludge production calculations for the treatment of primary effluent. In Ithaca, the primary settling tanks were overloaded at times and many of these solids were received at the pilot plant during the primary effluent phase, but the quantity was much less than otherwise would have been received.

A sludge production rate of 0.58 kg VSS/kg BOD_5 removed is within the range of values generally accepted for sludge production rates by conventional activated sludge systems. A sludge production rate of 0.81 kg VSS/kg BOD_5 removed would be typical of a high-rate activated sludge process (6)(30).

PROCESS CONTROL

Because of mechanical and operational problems, manpower requirements and training needs were greater than originally anticipated, twice necessitating revisions to the staffing arrangements. Initially, 20 man-hr/wk were allowed for operation of the pilot plant by City operators as part of the City's in-kind services contribution to the project. This burden was shared by several operators who received training during the startup period by Eco Technology personnel. With different operators working different shifts, it soon became apparent that a consistent operational control program could not be established. The staffing arrangements were revised to provide one operator with full responsibility for operation of the pilot plant after more intensive training. Approximately half of his time (20 hr/wk) was spent working at the pilot plant and the other half at the City's plant. Again, this proved to be unsatisfactory, particularly on weekends, evening shifts, or times when mechanical breakdowns or operational problems were encountered. The second revision in staffing arrangements was to provide a full-time Resident Project Coordinator whose sole responsibility was to operate the pilot plant 7 days/wk with latitude provided for overtime, if necessary. His duties included providing coordination with the City's operators concerning duties to be performed at the pilot plant by them and operations at the main plant affecting the pilot plant. In addition, the Resident Project Coordinator was required to perform analytical work to assist in operating the system. Consequently, approximately 25 to 30 man-hr/wk were expended in plant operation and approximately 10 to 15 man-hr/wk in laboratory work.

The system proved to be more complicated to operate in an effective manner than originaly anticipated. This was partially due to the abnormal number of mechanical breakdowns and instrumentation malfunctions that occurred. It was also due, however, to the amount of operator understanding and judgement required to make effective operating decisions. Daily control variables included float solids wasting, sink solids wasting, sink recycle rate, float skimmer speed, addition of flotation aids, and sink recycle by pump or gravity return. In addition, the shaft air distribution was varied a few times during the course of the study. The primary means of controlling the process was by controlling the solids inventory. Various control tests and observations were utilized to assist the operator in judging the quantity and source of solids to be wasted from the system. Shaft MLSS tests were run on a daily basis and MLVSS tests on an intermittent basis. Suspended solids tests were run on all tankfuls of float and sink waste sludge. Suspended solids concentrations of float recycle and sink return were determined on an intermittent basis. Visual observations were made of the float blanket, including color and length. The approximate thickness of the float blanket was determined using a suspended solids probe. Flotation tests were run daily on mixed liquor samples taken from R_2 (before swirl tank) and the flotation tank feed (after swirl tank). These tests provided a rough indication of the mixed liquor solids inventory and the relative proportions of solids floating and sinking. Settling tests were run daily on sink recycle samples and provided information on the quantity of sink solids. Effluent suspended solids were also analyzed daily by the operator. The operator was required to make his daily operating decisions with all these factors in mind. A delicate balance appeared to exist in controlling the system as the float blanket was easily disrupted. It became dispersed at times for no apparent reason, and dispersed flocculant solids were carried over the weir. At times, the blanket would begin to thin out and then reappear the following day. Consequently, a thorough understanding of the process and a great deal of operator attention and judgment were required to achieve effective process performance.

Jar tests of the flotation feed and R_2 mixed liquor samples indicated the superior flotation ability of mixed liquor prior to the swirl tank. In venting large gas bubbles in the swirl tank, apparently smaller bubbles that assist in flotation were vented as well. With an Eco III design, the swirl tank has been eliminated and should result in superior flotation performance. Large gas bubbles are collected by a baffle and vented directly out of the head end of the flotation tank.

NUTRIENTS AND METALS

As previously discussed, phosphorus removal by alum addition was attempted for a short time period and discontinued because of the disruption to the float blanket. Previous to that phase of the study and afterwards, phosphorus analyses were periodically conducted to establish background levels of phosphorus concentrations and to ensure that there was not a phosphorus deficiency in the influent to the pilot plant. Data collected during plant startup indicated that orthophosphorus concentrations in the influent were low particularly during the twice weekly digester "dump" periods, suggesting the possibility of a phosphorus limitation. It was suspected that the return of filtrate containing ferric chloride from plant sludge dewatering operations and industrial discharges to the City's collection system containing high concentrations of ferric ions was tying up available phosphorus.

Analyses of orthophosphorus concentrations in the pilot plant influent and effluent during the course of the study did not indicate a phosphorus limitation on 24-hr composite samples. However, because orthophosphorus data gathered during the startup period indicated the possibility of a phosphorus limitation during digester "dump" periods (19), phosphorus supplementation was provided on different occasions. Some analyses shown in the Appendices reflect the addition of phosphorus since, at times, the influent sampling point was located downstream of the point of supplementation. Although the character of the float blanket changed, there did not appear to be any improvement in process performance with phosphorus supplementation and it was discontinued each time it was tried.

Nitrogen concentrations, of course, were far in excess of those required for biological growth. Because the Deep Shaft process is a high-rate process with short SRT's, significant nitrification was not expected during the project. Effluent nitrate concentrations indicate that partial nitrification was achieved toward the end of the study during warmer weather. The effluent nitrate nitrogen concentration increased from 0.26 mg/l in the beginning of June 1981 to almost 11 mg/l by the end of the month.

Analyses of heavy metals were occasionally conducted on pilot plant influent because of the suspected discharges of acid wastes from a local industry. No significant concentrations were detected except for iron and that reflected the return of vacuum filtrate containing ferric chloride and industrial waste discharges containing iron.

SECTION 9

PROPRIETOR'S CLAIMS

A number of claims have been made in the literature primarily by Eco Technology regarding process and cost advantages of the Deep Shaft process (5)(12)(13)(14)(15)(17)(26). This section summarizes some of the claims that have appeared in the literature and compares them to the results obtained at the Ithaca pilot plant. It should be noted that a number of these claims were made while the Deep Shaft process was still under research and development in progressing from an Eco I design to an Eco III design. It should also be noted that not all of the operating results for the Ithaca pilot plant can be considered typical of the Deep Shaft process because of the numerous problems encountered and the unusual nature of the influent wastewater; more substantive results may be available from full-scale applications.

HIGH-RATE PROCESS

The Deep Shaft process is claimed to be a high-rate, high-intensity, high-oxygen transfer process. The mean DO level may be 10 to 20 mg/l with a peak of 40 mg/l at the bottom of the shaft. Depending on the depth of the shaft, the operating pressure at the bottom may be 5 to 15 atm., representing a 5- to 15-fold potential increase in oxygen solubility. The increased pressure results in a higher driving force for oxygen transfer. High turbulence levels minimize diffusional resistance to mass transfer. The oxygen utilization efficiency is claimed to be 70 percent compared to 5 to 15 percent for conventional activated sludge systems. The oxygen transfer intensity is said to be 3 kg $O_2/m^3/hr$ (0.19 $lb/ft^3/hr$), or more than 10 times that of conventional systems. This intensity level is achieved by a combination of three factors: high pressure, high bubble contact time, and high turbulence. Oxygen utilization is the limiting process parameter with Deep Shaft rather than oxygen transfer as with conventional systems, resulting in higher kinetic rates. MLVSS operating levels approaching 10,000 mg/l, and F/M loadings of 0.5 to 2.0 kg BOD_5/day/kg MLVSS may be achieved (13)(25)(26).

The Deep Shaft system at Ithaca operated as a high-rate activated sludge process. F/M loadings were in the range of 0.5 to 1.0 kg BOD_5/day/kg MLVSS. MLSS concentrations varied between 5,000 and 10,000 mg/l. Volumetric organic loadings ranged from 2.2 to 4.9 kg BOD_5/day/m^3 (137 to 304 lb/day/1000 ft^3). The following criteria are typical design ranges for conventional activated sludge systems:

F/M loading = 0.2 to 0.4 kg BOD_5/day/kg MLVSS
MLSS = 1,500 to 3,000 mg/l
Volumetric loading = 0.3 to 0.6 kg BOD_5/day/m^3
(20 to 40 lb/day/1000 ft^3)

POLYMER ADDITION

The use of polymer as a flotation aid was considered a necessity with an Eco I design. As a result of improvements brought about by Eco II and Eco III designs, it is claimed that the need for polymer or other flotation aids is reduced or eliminated. If required, careful process monitoring is required to ensure application of the optimum coagulant dosage. The cost of flotation aids, if used, may be partially offset by improved dewatering of waste sludge (6)(13).

The Deep Shaft system at Ithaca was operated the majority of time without the benefit of flotation aids. Polymer addition was desirable at various times and did serve to improve flotation and to develop a good, thick float blanket when necessary.

PRIMARY TREATMENT AND SOLIDS SEPARATION

Primary clarification and fine screening are not required with the Deep Shaft process. Coarse screening and degritting ahead of the shaft are recommended. Because ample air is provided for shaft circulation and because waste solids should not require additional thickening, it is more economical to eliminate primary settling (13)(26).

It is also suggested that higher hydraulic overflow rates can be used in the design of the solids separation unit compared to conventional systems because particle rise rates are higher than particle settling velocities (12).

The Deep Shaft process at Ithaca treated raw wastewater without primary settling for most of the study period. Primary settling, however, was required on an intermittent basis to reduce the impact of sludge processing streams recycled back to the head of the main plant.

The hydraulic overflow rate of the flotation tank at Ithaca at average design flow was 20.1 m^3/day/m^2 (494 gpd/ft^2). Typical design criteria for secondary clarifiers following air activated sludge are surface overflow rates of 16.3 to 32.6 m^3/day/m^2 (400 to 800 gpd/ft^2) at average design flow and 40.7 to 48.9 m^3/day/m^2 (1,000 to 1,200 gpd/ft^2) at peak design flow (28).

SLUDGE THICKENING AND DEWATERING

It is claimed that no additional sludge thickening is required with the Deep Shaft process because a float solids concentration of 4 to 10 percent can be achieved (5). In addition, improved sludge dewatering can be obtained due to the absence of long chain filamentous organisms (13)(26).

The waste float solids concentration achieved at Ithaca ranged from 1.6 to 4.8 percent. In addition, the quantity of sink solids wasted often exceeded the quantity of float solids wasted. Sink solids wasted generally had a solids concentration of approximately 2 percent. Therefore, the total quantity of sludge wasted generally had a solids concentration of 2 to 4 percent depending on the proportion of wasting from both sources.

No sludge dewatering tests were conducted as part of the official project experimental program. Eco Technology did sponsor a series of centrifugation dewatering tests performed by Sharples, Inc.

SLUDGE PRODUCTION

The quantity of sludge produced is claimed to be substantially less than than for other high-rate activated sludge processes and is comparable to extended aeration (5). Sludge production has been estimated at 0.5 to 0.65 kg SS/kg BOD_5 removed. The explanation for lower sludge yields is not entirely clear but is related to the metabolic cycle of biomass and plug flow operation. The unusual environment in the shaft causes an increased bacterial respiration rate; more organic carbon is converted into carbon dioxide and less into living matter (13)(26).

Sludge production rates determined at the Ithaca pilot plant did not indicate a reduction in sludge production compared to conventional activated sludge systems. The calculated rates, however, may be misleading because of the large quantity of digester solids entering the system.

SPACE REQUIREMENTS

It is claimed that land area requirements can be reduced by 10 to 30 percent with the Deep Shaft process. Because the Deep Shaft process is a high-rate process, a 5- to 20-fold reduction in bioreactor volume can be achieved. Land area requirements can also be reduced by the elimination of primary settling tanks and sludge thickeners (5)(13)(26).

Land area requirements would have to be determined on a case-by-case basis depending on the treatment requirements and necessity or desirability of utilizing primary settling tanks or sludge thickening, but in any event would be less because of the small surface area required for the shaft itself.

SHOCK LOADS AND TREATMENT MODEL

The Deep Shaft process is capable of handling large organic and hydraulic fluctuations. Shock loads are handled well because of the high bacterial concentrations maintained within the shaft and high internal recycle rates that ensure stable operation and near-instantaneous dilution of transient concentration fluctuations.

The process is patterned after a plug flow model, but the overall effect is the operational stability associated with completely mixed aeration basin designs. A very high internal recycle effects a 10- to 50-fold dilution of influent wastewater during each cycle. With the Eco II and Eco III designs, single-pass plug flow treatment time is maximized in a high-intensity, aerobic environment (12)(26).

The Ithaca pilot plant did handle shock loadings resulting from digester "dumps" very well. The process was disrupted on a short-term basis and recovered within 12 to 24 hr. The pilot plant designed for Ithaca, however, was not capable of handling large hydraulic fluctuations. The maximum sustained peaking factor above average design flow was approximately 1.4 with adequate allowance for recycle flows. The total shaft capacity for all flows was approximately double its design flow. The impact of short-term peak flows simulating wet-weather conditions could not be tested because of the system's hydraulic limitations.

ENERGY REQUIREMENTS

Energy requirements are claimed to be less with the Deep Shaft process compared to conventional systems. A peak aeration efficiency of 3.3 kg O_2/kWh (5.5 lb/wire hp-hr) is claimed. Because a minimum amount of air is required for shaft circulation, power economy increases with increasing influent strength (12)(26).

The energy requirements at Ithaca cannot be scaled up to full-scale Deep Shaft applications because of the small diameter of the Ithaca shaft. Power requirements for shaft circulation were proportionally higher because of the increased head losses caused by skin friction with the shaft casing.

CAPITAL AND OPERATING COSTS

Capital costs for the Deep Shaft process are said to be less than that for conventional activated sludge systems while operating costs are no greater. Capital cost savings result from the elimination of primary settling and sludge thickening units and return sludge pumping systems. Savings in operating costs may result from lower energy requirements, a semi-attended operating basis, and gravity sludge return with an attendent decrease in pumping requirements (5)(12)(26).

The capital and operating costs for the Ithaca demonstration plant cannot be used to scale up cost estimates for full-scale Deep Shaft applications. Economic considerations would probably vary widely on a case-by-case basis.

COLD WEATHER OPERATION

The Deep Shaft process is located completely indoors and, therefore, is not physically affected by cold air temperatures. The exposed bioreactor surface area is very small as 90 percent of the volume is below ground; therefore, heat loss is minimized (13)(26).

The Deep Shaft system at Ithaca was located totally indoors. During cold weather operations, the process was influenced only by the temperature of the incoming wastewater. The lowest wastewater temperature recorded at Ithaca during the evaluation period was 9°C.

The need for flotation tank protection is a function of local weather conditions. In cold climates, the flotation tanks must be housed indoors to protect the float blanket against freezing. In climates with rain but no freezing temperatures, covers over the flotation tanks would be sufficient to prevent the rain from disrupting the float blanket. In arid climates, covers would not be necessary.

BULKING SLUDGE

With adequate nutrient levels, it is claimed that no growth of filamentous microorganisms will occur in the Deep Shaft process because of the high DO environment and the extremely turbulent conditions. DO levels of 40 to 50 mg/l in the lower region of the shaft with a Reynolds Number greater than 10^5 result in a highly aerobic, well oxygenated biomass that minimizes the development of filamentous organisms (26).

There was no evidence of the growth of filamentous organisms during the course of the evaluation period at Ithaca. This could be due in part to the short SRT's encountered, which minimize the time in which filamentous growths could become established.

OPERATIONAL SIMPLICITY AND CONTROL

The process is said to be simple to operate with no sophisticated process controls and designed for operation on a semi-attended basis by personnel with no previous experience in wastewater treatment and no special technical skills. Since no moving parts such as mechanical aerators or air diffusers are used in the shaft, reactor maintenance requirements are negligible. Staffing requirements for the Deep Shaft process are claimed to be similar to other processes. Being totally enclosed facilitates maintenance and provides for the comfort of personnel. Aesthetically, the Deep Shaft process is more acceptable because of its minimal visual impact and the elimination of odor and noise (13)(26).

The Deep Shaft system at Ithaca was not simple to operate and required a well-trained operator to make operational decisions. Manpower requirements were substantially increased by numerous mechanical breakdowns and operational problems that were independent of the Deep Shaft process itself. Manpower requirements do not appear to be less, and could be more, than for conventional systems.

Although initially the operators were relatively inexperienced in operating the system, they were well trained by the end of the experimental program.

SECTION 10

DESIGN AND OPERATING CONSIDERATIONS

Although more definitive information will be necessary from full-scale applications of the Deep Shaft process to allow detailed evaluations of the Deep Shaft process against other process alternatives for full-scale applications, a number of design and operating features were revealed by the Ithaca pilot plant study. This section briefly summarizes design and operating characteristics of the Deep Shaft process that should be considered in determining the applicability of the process at other locations, both municipal and industrial.

PRIMARY SETTLING TANKS

In determining the necessity of utilizing primary settling tanks ahead of the Deep Shaft process, consideration should be given to

1. the fact that no benefit is gained in reducing BOD_5 loadings to a Deep Shaft system as sufficient air is required for shaft circulation to satisfy influent BOD_5 concentrations up to 500 mg/l or greater (12),
2. cost savings associated with elimination of primary settling tanks,
3. reduced potential for rag accumulations in a Deep Shaft system with primary settling,
4. reduced process performance and flotation ability with dilute organic loading and lack of fibrous material,
5. reduced potential for scum accumulations or excessive foaming, and
6. benefits associated with capture of solids from various sources such as septage wastes, digester supernatant, backflush streams, sewer flushings, industrial wastes, wet-weather "first-flushes", etc.

REACTOR AND FLOTATION TANK DESIGN

In determining the feasibility of the process to a particular application, consideration should be given to

1. hydraulic range requirements and the necessity or desirability of equalization facilities ahead of the system and
2. reliability design criteria requirements regarding component backup, system hydraulic flexibility, emergency situations, and provisions for future expansion or upgrading.

FLOTATION AIDS

The desirability of providing a polymer feed system to aid in flotation on an intermittent or seasonal basis, if required, should be considered in all applications.

PHOSPHORUS REMOVAL AND NITRIFICATION

1. Tertiary facilities may be required for phosphorus removal, resulting in additional costs compared to conventional systems. This decision will depend on the yet-to-be-determined compatibility of in-process alum or iron addition with Deep Shaft operations when treating raw wastewater.
2. Second-stage facilities may be necessary with the Deep Shaft process to achieve nitrification if it is required as with most other biological treatment alternatives. The considerations involved in choosing between single- and two-stage systems would be similar to those involved with other biological systems.

SLUDGE THICKENING AND TREATMENT

1. The volume and concentration of sludge for sludge processing operations will be largely dependent on float blanket thickness and the proportion of sink wasting.
2. The need for sludge thickeners will depend on float blanket thickness and the proportion of sink wasting.

PROCESS OPERATION AND CONTROL

1. As with other processes, operators must be thoroughly trained to understand the hydraulics of a Deep Shaft system and interrelationships of system components as well as process fundamentals.

2. Careful control of solids inventory and attention to solids wasting from float and sink blankets are the main factors in maintaining a healthy float blanket and controlling the process.
3. Observations of float blanket length and thickness, mixed liquor flotation tests, sink recycle settling tests, and MLSS concentrations are routine daily tests required to accurately assess sludge wasting requirements.

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APPENDIX A

DAILY ANALYTICAL DATA AS REPORTED BY COMMERCIAL LABORATORY

Notes: All values in mg/l.
T = Total
S = Soluble
T-un. = Total unseeded BOD_5
NO_3-N = NO_3-N + NO_2-N except where reported separately.
Commercial Laboratory - Water Testing Laboratory, Inc.

TABLE A-1. DAILY ANALYTICAL DATA
October 1979

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16	105	10	17	7	306	27	66	15	170	4	100	4		
17														
18		13			917	65			1070	21				
19														
20														
21														
22		19		5	493	99			293	27				
23														
24														
25	174	14		6	749	54		43	470	10				
26														
27														
28														
29														
30														
31	109	12		3	281	68			132	34				

(continued)

TABLE A-1. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16			2.55	0.50			14.5	13.0	24.6	17.5	9.00	0.06	0.05	0.01
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE A-2. DAILY ANALYTICAL DATA
November 1979

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	178	25		3	259	126			680	88				
2														
3														
4	136	9		3	572	68			640	11				
5	106	11		5	274	79			48	2				
6	154	13	8	12	331	83	36	40	128	25	1	1		
7	97	10		4	310	58			236	40			2.1	
8	211	18		11	900	47			800	45			32.4	
9														
10														
11	88	20			50	18			135	28			7.5	
12	156	23	31	4	706	43	54	7	640		370		25.2	
13	48	22		4	243	118			183	54			2.1	
14	63	20		5	380	132			240	39			3.1	
15	114	31			711	174			650	73			7.0	
16														
17														
18	113	45		4	371	147			490	187				
19	115	30		17	288	125			300	92				
20														
21														
22														
23	62	32		8	270	202			213	220	213	137		
24	38	22		2	202	151			130	126	130	96		
25	72	25		7	1010	162			1060	157	640	123		
26														
27	63	22							187	98				
28	96	30							168	74				
29	174	21							333	44				
30														
31														

(continued)

TABLE A-2. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4	0.57	5.50	15.00	14.00										
5	1.40	2.32	5.00	21.00										
6	1.02	2.75	11.00	11.00			12.1	10.9	26.3	14.0	--	2.80	<0.04	0.13
7	1.37	0.66	13.00	2.00										
8	0.65	1.02	2.50	8.00										
9														
10														
11	4.60	2.60	8.30	3.40										
12	2.00		17.00				20.7		52.4		0.04		<0.04	
13	4.80	1.80	15.00	2.50										
14	4.35	3.10	7.50	6.00										
15	6.40	2.25	7.50	5.00										
16														
17														
18	1.27	1.03	5.10	4.50										
19	1.67	0.75	4.40	2.75										
20														
21														
22														
23	1.94	1.43	4.40	4.50										
24	1.88	2.30	3.45	3.00										
25	7.10	0.73	27.5	3.30										
26														
27														
28														
29														
30														
31														

TABLE A-3. DAILY ANALYTICAL DATA
December 1979

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2	132	34							207	144				
3	150	39							247	148				
4	138	34							248	178				
5	342	42							456	174				
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE A-4. DAILY ANALYTICAL DATA
May 1980

	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
Date	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19	179		12		501		28		410		320		18.1	
20		8		2		34		11		6		6		
21														
22	69	8			128	42	48	13	94	26	42	1	2.2	
23														
24														
25	32	20			54	46	27	4	42	16	1	1	0.4	
26	37	20			57	34	11	4	72	68	18	14	1.6	
27	60	7	7	7	140	59	79	53	72	8	64	8	2.2	
28	120	21	24	6	272	72	83	64	87	28	87	10	3.8	
29	112	25	26	9	344	136	68	53	307	92	162	32	10.0	
30	26	10			162	126			56	2	10	1	1.2	
31	31	22			184	126			60	20	42	10	1.3	

(continued)

TABLE A-4. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19	12.00				14.50									
20		7.80				8.50								
21														
22	7.80	6.50			9.50	7.50								
23														
24														
25	8.80	6.50			11.00	15.00								
26	8.80	6.50			14.00	8.00								
27	1.00	2.50			17.50	6.50								
28	2.40	1.00			4.50	9.00								
29	5.00	4.00			4.00	4.70								
30	6.75	2.40			10.50	4.00	12.5	8.2	17.1	9.6	2.11	0.03	0.45	0.15
31	2.25	3.85			10.00	13.50	17.2	8.8	20.1	11.3	2.75	0.25	1.15	0.15

TABLE A-5. DAILY ANALYTICAL DATA
June 1980

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	66	14			317	144			67	15	10	1	4.7	
2	144	24	24	8	479	155	191	119	393	10	360	1	48.7	
3	119	18			426	74			295	13			7.3	
4	70	19			156	63			133	8			4.0	
5	35	30			164	74			67	29			2.8	
6														
7														
8														
9	77	24	4	1	216	36	58	25	300	34	195	1	4.3	
10	96	14			187	26			100	11			5.2	
11	175	29			353	29			290	11			10.4	
12	102	29			191	36			125	16			6.1	
13														
14														
15														
16	96	27			342	119			187	24				
17	41	13			122	50			68	11				
18	63	12			176	50			83	13				
19	68	13	21	5	194	61	65	40	120	9	113	5	1.7	
20														
21														
22	50	20			151	38			168	38			1.9	
23	116	15	13	3	272	30	53	30	236	31	180	31	4.7	
24	57	20			184	40			106	24			1.9	
25	49	19			191	29			123	14				
26														
27														
28														
29	133	14		2	380	36			275	1			10.6	
30	141	29	20	3	284	48	72	48	123	8	107	8	2.8	
31														

(continued)

TABLE A-5. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	2.50	1.98			4.50	4.20	14.8	12.3	22.5	12.9	1.89	0.05	1.65	0.15
2	4.13	2.63			4.70	20.00	14.8	10.4	26.4	13.7	1.52	0.01	1.00	0.15
3	3.25	0.75			3.75	1.50								
4	0.50	2.35			1.00	2.00								
5	0.75	0.50			4.50	3.75								
6														
7														
8														
9	2.75	2.50			3.00	3.00	13.1	17	18.6	18.1	10.8	8.6	0.03	0.12
10	7.00	4.10			7.20	4.50								
11	7.00	6.60			8.00	7.00								
12	7.70	3.90			8.20	4.00								
13														
14														
15														
16	5.50				6.00									
17	0.80	1.10			1.30	2.10								
18	1.20	0.80			1.60	1.00								
19	0.80	1.40			1.40	2.70	8.7	4.1	16.0	7.5	11.6	4.0	0.02	<0.04
20														
21														
22	1.80	1.0			1.80	1.40								
23	1.40	1.6			1.80	1.70	12.5	8.5	17.0	11.2	10.0	0.4	5.1	0.02
24	1.86	1.10			9.20	1.20								
25	2.10	0.76			2.40	0.80								
26														
27														
28														
29	4.25	0.60			4.60	0.80								
30	2.60	1.50			3.00	1.90	7.8	4.7	16.6	6.6	<0.04	<0.04	0.01	0.01
31														

TABLE A-6. DAILY ANALYTICAL DATA
July 1980

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	100	13		2	360	42			205	4			3.0	
2	107	10		4	250	46			145	8			3.2	
3														
4														
5														
6	70	13	17	8	333	34	55	28	180	44	135	34	3.1	0.8
7	124	17	16	5	350	55	34	21	195	16	155	13	2.8	0.5
8	171	10		1	473	41			340	22			6.2	
9	133	9		1	312	75			267	35			3.3	
10	146	9		1	409	113			413	12			11.3	
11														
12														
13														
14	138	23		1	882	76		63	730	69				
15														
16	81				384				335					
17	94				335				260					
18		13		2		68				24				
19														
20	77	45		4	300	63			130	27				
21	107	13		1	465	72			365	18				
22	55	17		13	182	102			230	37				
23	96	19		11	183	102			450	30				
24	39	18		14	175	115			192	47				
25														
26														
27	92	41	18	9	444	53	72	49	190	17	115	10		
28	105	38	25	6	267	73	89	36	180	21	135	14		
29	51	25	8	4	116	76	31	31	120	53	92	43		
30	125	28	17	4	232	58	76	9	235	59	105	41		
31	36	29	13	7	98	80	54	18	90	56	68	45		

(continued)

TABLE A-6. (continued)

Date	Ortho-P Inf.	Ortho-P Eff.	Tot. P Inf.	Tot. P Eff.	Tot. P (S) Inf.	Tot. P (S) Eff.	NH_4-N Inf.	NH_4-N Eff.	TKN Inf.	TKN Eff.	NO_3-N Inf.	NO_3-N Eff.	NO_2-N Inf.	NO_2-N Eff.
1	3.05	0.06			3.50	1.40								
2	3.00	1.10			3.30	6.60								
3														
4														
5														
6	2.04	0.75	3.90	1.40	1.90	0.80	15.2	6.1	30.4	8.6				
7	2.75	1.00	4.40	1.55	2.30	1.50	12.2	6.7	21.0	8.1				
8	3.00	1.25	7.30	1.50	3.20	1.30								
9	3.90	1.75	5.60	4.00	3.50	1.40								
10	6.85	1.15	8.30	1.90	2.70	1.30								
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21							9.5	6.2	24.1	8.6				
22														
23														
24														
25														
26														
27	2.60	1.10			3.00	1.50	14.8	10.0	22.3	12.5				
28	2.10	1.10			2.50	1.50	9.5	6.1	17.3	9.1				
29							7.1	2.1	12.7	5.3				
30							10.4	4.1	19.2	8.4				
31							13.9	8.9	20.2	12.9				

TABLE A-7. DAILY ANALYTICAL DATA
August 1980

Date	BOD_5 (T) Inf.	BOD_5 (T) Eff.	BOD_5 (S) Inf.	BOD_5 (S) Eff.	COD (T) Inf.	COD (T) Eff.	COD (S) Inf.	COD (S) Eff.	SS Inf.	SS Eff.	VSS Inf.	VSS Eff.	Fe (T) Inf.	Fe (T) Eff.
1														
2														
3	75	19		5	107	98			42	14				
4	119	15		8	630	49			75	16				
5				4	491	119			150	61				
6	91	51		4	278	88			370	31				
7	88	34		11	234	84			102	68				
8														
9														
10	45	37		4	119	72			195	48				
11	61	62		5	239	89			114	48				
12	55	17		3	292	59			285	33				
13	70	14		4	288	17			270	90				
14	56	17		4	186	58			265	52				
15														
16														
17	136	41		7	264	98			125	41				
18	143	23		5	199	69			137	41				
19	75				240				143					
20	120	28		4	257	63			205	38				
21	83	24		4	253	94			170	35				
22														
23														
24	114	21	8	12	223	38	38	21	113	22	80	18		
25	84	44	21	5	265	97	59	21	150	43	117	26		
26	91	66			202	147			280	24				
27	115	44	18	12	286	55	38	42	105	31	40	17		
28														
29														
30														
31	88		17		340		247		140		60			

(continued)

TABLE A-7. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11							9.9	5.3	15.7	8.3				
12														
13														
14														
15														
16														
17							9.7	1.8	18.4	6.1				
18							9.2	1.6	15.9	4.5				
19														
20														
21														
22														
23														
24							10.0	2.1	17.9	5.4	0.23	5.20		
25							12.8	4.4	21.0	9.0	0.04	4.60		
26														
27							12.4	2.0	21.4	4.1	5.00	1.09		
28														
29														
30														
31							13.1		23.2					

TABLE A-8. DAILY ANALYTICAL DATA
September 1980

Date	BOD$_5$ (T) Inf.	BOD$_5$ (T) Eff.	BOD$_5$ (S) Inf.	BOD$_5$ (S) Eff.	COD (T) Inf.	COD (T) Eff.	COD (S) Inf.	COD (S) Eff.	SS Inf.	SS Eff.	VSS Inf.	VSS Eff.	Fe (T) Inf.	Fe (T) Eff.
1		51		2		162		52		44		28		
2	66	28		7	333	50			168	37				
3	61	20		13	261	61			120	46				
4	109	59		6	287	49			144	3				
5														
6														
7	90	42		3	314	95		36	300	81				
8														
9	58	23		3	249	65			160	26				
10	147	21		3	453	65			275	41				
11	123	16		3	311	81			185	57				
12														
13														
14	198	28	19	2	362	62			520	83				
15	137	47	26	2	323	85			505	140				
16														
17														
18														
19														
20														
21	176	17	37	1	634	45	140	31	560	53	412	32		
22	152	60	19	2	453	118	93	30	588	115	416	72		
23	138		22		445		161		508		320			
24	122	33	18	3	441	146	154	87	444	101	256	58		
25														
26														
27														
28		36		3		46				34				
29	186	72		4	650	85			532	86				
30	150	44		3	633	74			632	73				
31														

(continued)

TABLE A-8. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2								4.9		8.6	3.50	1.50		
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16							14.3	8.0	26.8	12.8	4.50	0.20		
17														
18														
19														
20														
21														
22														
23							13.7	8.6	26.9	13.8	3.40	3.90		
24														
25														
26														
27														
28														
29														
30							16.7	10.6	35.2	11.8	3.90	1.48		
31														

TABLE A-9. DAILY ANALYTICAL DATA
October 1980

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	165	43		2	666	119			452	91				
2	149	42		2	375	121			272	103				
3														
4														
5	89	59			272	155	89	27	328	192				
6	140	22			379	46	101	23	488	72				
7	112	26		3	217	24			300	45				
8	171	26		5	419	36			332	54				
9	142	23		4	326	70			288	41				
10														
11														
12	93	26		2	181	47			96	11				
13	76	27		3	213	47			88	20				
14	141	30		2	324	95			252	50				
15	186	49	2	3	466	130			646	75				
16														
17														
18														
19	199	35		2	478	64			500	71				
20	222	68		3	616	115			624	153				
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE A-10. DAILY ANALYTICAL DATA
November 1980

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9	190	18			357	52			260	26				
10	103	29			244	66			144	53				
11	111	49		3	322	68			218	124	18	24		
12	84	29			192	34			125	28				
13	85	42			212	108			160	54				
14														
15														
16	76	35			191	44			84	32				
17	83	29			227	56			123	33				
18	112	42			243	51			184	37				
19	115	25			219	51			84	42				
20	95	25			211	43			207	33				
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

(continued)

TABLE A-10. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11							13.2	9.1	20.4	17.1	0.50	6.90		
12														
13														
14														
15														
16														
17														
18							13.5	8.8	22.2	12.3	0.55	2.82		
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE A-11. DAILY ANALYTICAL DATA
December 1980

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7	77	29			237	68			119	43				
8	247	63		5	421	102			325	106				
9	75	40			230	72			86	36				
10	114	36			245	58			106	28				
11	79	32			198	83			86	19				
12														
13														
14	84	70			224	111			150	123				
15	90	48		2	225	91			98	55				
16	115	34			223	56			125	24				
17	114	41			260	62			89	25				
18	105	37		3	236	52			56	16				
19														
20														
21	70	25			180	58			116	33				
22	62	33			148	61			106	51				
23	60	28		3	151	50			110	35				
24														
25														
26														
27														
28														
29	53	25			151	47			86	26				
30	59	23		1	162	33			92	29				
31	49	9			100	46			60	6				

(continued)

TABLE A-11. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8							13.4	5.5	30.4	11.8	<0.04	4.88		
9														
10														
11														
12														
13														
14	2.20	1.86	2.56	3.74										
15	2.46	1.96	3.50	2.96			14.5	5.0	22.0	9.4	<0.04	5.84		
16	2.60	0.70	3.64	1.48										
17	2.30	1.36	3.54	1.89										
18	2.06	1.70	3.16	2.08										
19														
20														
21	2.06	0.46	3.16	1.40										
22	2.00	0.76	2.98	1.70										
23	2.10	0.50	2.76	1.36			9.0	5.0	14.6	8.2	0.48	4.16		
24														
25														
26														
27														
28														
29	2.00	0.86	2.68	1.04							0.74	3.92		
30	1.96	1.26	4.88	2.33			7.6	4.9	13.1	6.8				
31	1.94	0.68	2.70	0.70										

TABLE A-12. DAILY ANALYTICAL DATA
January 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	51	9			154	30			53	9				
2	44	13			116	41			41	10				
3														
4	36	23			103	42			63	25				
5	46	24		2	147	33			53	14				
6	71	27			207	35			126	29		20		
7	68	16			170	23			96	17		12		
8	91	49			264	79			138	45				
9														
10	94	61			205	69			156	71				
11	60	32			134	34			106	29				
12	79	49		3	200	68			130	56	66	33		
13	63	33			160	57			58	23				
14	92	18			247	42			107	12				
15	73	17			137	39			91	9	80	8		
16														
17														
18	56	18			146	28			68	13				
19	81	25		3	210	43			85	11	73	9		
20	69	13			207	50			66	4				
21	54	25			155	49			27	17				
22	68	19			187	95			46	20				
23														
24														
25	150	32			322	63			228	20				
26	71	32	20	3	163	67			202	13	65	12		
27	124	34			488	92			148	46				
28	104	33			244	115			106	50				
29														
30														
31														

(continued)

TABLE A-12. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	2.10	0.78	3.16	0.90										
2	1.80	0.80	2.60	0.84										
3														
4	2.06	1.69	2.82	2.70										
5	1.80	0.92	2.57	1.42			9.1	4.7	14.2	6.6	0.38	4.72		
6	3.16	1.26	3.24	1.60										
7	2.73	1.09	3.18	1.40										
8	3.14	1.64	4.01	2.38										
9														
10	3.00	2.03	3.87	3.17										
11	2.50	1.64	3.26	2.10										
12	2.54	1.43	3.74	2.67			9.5	6.5	15.3	10.9				
13	3.40	0.64	4.06	1.26										
14	3.36	0.26	4.09	0.81										
15	3.04	0.39	4.06	0.82										
16														
17														
18	2.80	0.27	3.38	0.66										
19	3.64	1.01	4.33	1.42			11.0	6.9	16.8	9.4				
20	3.40	0.20	4.23	0.62										
21	2.90	0.86	3.23	2.15										
22	2.80	0.27	3.77	1.42										
23														
24														
25														
26							12.4	8.7	18.7	11.5	<.04	5.80		
27														
28														
29														
30														
31														

TABLE A-13. DAILY ANALYTICAL DATA
February 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19	137	31	42	4	262	88	79	58	210	70	111	40		
20														
21														
22	148	15	23	2	201	52	51	32	207	34	168	21		
23														
24	73	23	21	2	186	61	59	38	176	49	116	32		
25	80	19	28	3	189	44	59	32	130	42	92	29		
26	90	40	33	12	217	104	72	37	106	49	90	37		
27														
28														
29														
30														
31														

(continued)

TABLE A-13. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19											0.61	1.63		
20														
21														
22	4.00	0.90	6.34	2.25			10.2	5.3	20.1	7.8	<0.04	2.04		
23														
24	2.43	0.71	3.29	1.73			8.0	3.9	13.3	7.0	0.91	2.75		
25	2.72	0.57	4.02	1.40			9.7	5.6	15.0	8.2	0.80	3.53		
26	2.79	0.78	3.52	1.92			9.7	9.0	15.9	13.1	0.77	2.75		
27														
28														
29														
30														
31														

TABLE A-14. DAILY ANALYTICAL DATA
March 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	111	23	31	5	245	68	67	30	205	88	200	58	6.5	
2	182	27	33	5	374	75	53	53	310	58	225	42	11.8	
3	116	21	43	4	295	96	79	29	198	35	142	24	6.9	1.0
4	135	24	38	3	272	88	62	42	213	38	180	35	4.0	1.1
5	165	17	36	5	318	69	61	19	335	47	245	30	11.6	1.0
6														
7														
8														
9	146	24	44	10	361	81	81	38	173	47	107	30		
10	160	33	51	5	430	98	95	29	264	20	204	12		
11	136	23	47	4	269	68	65	17	108	34	62	23		
12	152	24	50	4	307	74	67	13	154	39	126	36		
13														
14														
15	248	31	35	3	530	90	79	31	296	30	252	27		
16	175	36	41	3	406	113	107	40	188	51	144	35		
17														
18														
19														
20														
21														
22														
23														
24	192	98	112	8	371	110	148	42	187	79	161	76		
25	167	48	59	8	366	146	104	43	237	74	140	56		
26	155	29	62	3	377	91	134	45	180	51	117	36		
27														
28														
29	149	72	28	2	472	107	67	33	280	61	212	41		
30	144	24	40	2	413	70	92	41	344	43	260	32		
31	84	22	21	3	293	88	59	38	253	60	137	43		

(continued)

TABLE A-14. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	4.49	1.29	5.94	2.15			10.3	9.2	20.0	13.0	0.76	2.19		
2	6.50	2.16	7.46	3.32			12.3	8.0	21.0	10.0	0.64	1.63	0.26	0.11
3	2.59	0.97	4.31	1.59			15.6	10.8	23.0	14.0	<0.04	1.20		
4	2.38	0.91	4.38	1.73			14.1	9.9	20.0	13.0	<0.04	1.42		
5	2.59	0.40	5.64	1.05			12.8	9.4	22.0	13.0	0.43	1.60		
6														
7														
8														
9	2.19	1.01	4.33	1.45			13.8	8.8	23.0	13.0	0.20	1.88		
10	3.50	1.24	5.46	1.82										
11	2.68	1.13	4.60	1.34										
12	2.99	1.34	4.79	1.68										
13														
14														
15	2.32	0.77	2.49	0.81										
16	1.75	0.57	3.16	0.72			18.3	10.9	27.0	15.0	<0.04	1.83		
17														
18														
19														
20														
21														
22														
23														
24	1.91	1.02	3.16	1.48			15.1	11.8	25.0	13.0	0.60	0.36		
25	2.11	0.62	3.04	0.95										
26	1.96	0.48	2.62	0.76										
27														
28														
29	2.83	1.67	5.67	2.28			10.4	10.2	18.9	15.3	<0.04	0.29		
30	2.86	1.34	5.23	3.12			12.6	10.8	23.6	14.7	<0.04	0.31		
31	2.41	1.13	3.58	1.77			10.7	8.8	17.5	13.3	1.69	0.04		

TABLE A-15. DAILY ANALYTICAL DATA
April 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	100	17	29	2	277	73	68	37	197	53	173	39		
2	86	16	25	2	242	71	62	35	96	19	72	11		
3														
4														
5	130	15	34	1	312	47	82	20	210	22	170	21	2.6	
6	209	15	69	2	526	60	128	27	533	41	325	34	14.6	
7	163	18	39	1	385	62	81	22	113	21	100	16	5.5	
8	146	21	56	2	296	71	92	36	140	19	112	13	5.3	
9	126	16	43	2	282	66	102	36	163	22	135	18	2.2	
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

(continued)

TABLE A-15. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		NO_2-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	2.09	0.62	2.31	1.09			10.9	7.8	18.3	11.6	0.50	<0.04		
2	1.91	0.92	3.29	1.34			10.4	8.5	17.1	12.2	1.09	0.55		
3														
4														
5	2.35	1.07	4.42	1.39			12.3	8.5	21.3	11.3	<0.04	2.14		
6	3.41	0.69	6.43	0.88			17.8	10.8	29.3	14.3	<0.04	1.89		
7	3.58	0.86	4.60	1.44			15.8	9.5	27.2	13.3	<0.04	1.62		
8	2.57	0.98	4.31	1.58			13.9	10.0	22.9	13.8	<0.04	1.38		
9	2.24	1.18	4.06	1.72			12.0	10.5	19.9	14.3	0.33	1.35		
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE A-16. DAILY ANALYTICAL DATA
June 1981

Date	BOD$_5$ (T) Inf.	BOD$_5$ (T) Eff.	BOD$_5$ (S) Inf.	BOD$_5$ (S) Eff.	COD (T) Inf.	COD (T) Eff.	COD (S) Inf.	COD (S) Eff.	SS Inf.	SS Eff.	VSS Inf.	VSS Eff.	BOD$_5$(T-un.) Inf.	BOD$_5$(T-un.) Eff.
1	136	7	28	4	369	53	62	40	215	5	165	5	128	12
2	113	6	18	4	371	57	52	25	252	13	200	12	139	12
3	86	6	16	4	271	50	46	36	208	14	172	14	148	13
4	93	8	17	3	314	55	64	32	259	17	157	14	138	13
5														
6														
7	96	9	17	2	238	43	50	32	170	21	112	12	71	9
8	94		22	2	344	61	52	33	194	19	124	10	83	36
9	87	12	16	3	201	39	39	32	174	15	123	13	78	12
10	78	12	19	2	211	52	41	37	163	18	117	12	70	12
11	96	15	20	2	232	50	58	30	218	22	121	11	100	15
12														
13														
14	119	35	18	3	283	63	197	63	342	91	222	59	98	27
15	90	31	24	3	197	63	48	30	246	76	154	49	68	26
16	84	29	12	2	212	62	48	31	329	58	123	22	78	23
17	112	27	17	3	249	62	55	29	362	50	135	22	99	26
18	70	27	20	3	205	64	57	36	126	33	90	19	68	25
19														
20														
21	65	25	15	4	163	54	45	23	118	35	80	24	62	25
22	111	27	25	2	302	62	72	27	214	42	164	24	109	27
23	83	17	15	2	355	56	58	27	226	21	187	19	101	19
24	73	21	11	1	219	60	56	31	160	28	134	18	72	23
25	78	18	13	5	251	50	63	35	156	20	130	15	91	19
26														
27														
28	36	30	6	5	135	42	31	23	41	31	41	24	38	31
29	47	19	11	7	158	42	42	34	81	18	77	18	45	22
30	59	28	14	6	199	41	38	26	82	16	80	16	65	30
31														

(continued)

TABLE A-16. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	2.46	0.87	4.54	1.05			12.3	11.4	20.5	13.5	<0.04	0.26		
2	3.07	0.84	4.06	0.92			12.5	10.9	20.3	12.9	<0.04	0.36		
3	2.24	0.72	3.14	0.78			11.5	9.7	18.6	11.9	<0.04	0.34		
4	2.31	0.67	3.73	0.74			8.9	8.4	17.6	10.6	0.33	0.56		
5														
6														
7	2.68	0.48	4.12	0.76			13.9	10.1	21.7	12.3	<0.04	1.28		
8	2.27	0.57	4.17	0.82			9.6	11.0	17.0	12.9	<0.04	0.91		
9	1.97	0.67	3.83	0.80			9.9	8.4	16.8	10.6	<0.04	0.84		
10	1.84	0.82	2.74	0.82			10.0	8.7	15.2	10.2	<0.04	0.98		
11	1.90	0.86	3.14	0.94			12.8	8.6	20.8	11.0	<0.04	1.10		
12														
13														
14	2.00	0.98	3.08	2.30			9.9	8.0	19.0	11.2	<0.04	2.77		
15	1.29	0.66	2.26	1.88			8.2	5.3	14.3	8.2	<0.04	2.73		
16	1.87	0.75	3.60	1.10			7.7	4.8	14.8	7.5	<0.04	3.32		
17	2.31	0.56	3.73	0.90			9.2	5.7	16.5	8.1	<0.04	3.54		
18	1.85	0.36	2.93	0.80			10.5	6.7	16.8	9.9	<0.04	3.35		
19														
20														
21	2.12	0.24	3.33	0.73			9.8	6.1	16.2	9.0	<0.04	3.08		
22	2.30	0.37	4.16	0.75			12.4	6.2	22.1	9.1	<0.04	2.46		
23	3.27	0.24	4.37	0.34			12.9	7.2	22.0	9.7	<0.04	3.91		
24	2.09	0.59	2.99	1.04			8.3	4.8	15.4	7.3	<0.04	4.12		
25	2.08	0.26	3.68	0.48			11.5	5.5	20.3	8.2	<0.04	4.95		
26														
27														
28	1.80	1.34	2.87	1.51			9.4	3.5	15.0	6.5	0.75	7.63		
29	1.72	1.11	3.06	1.24			12.3	2.2	17.3	5.3	0.59	8.98		
30	2.17	1.43	4.02	1.75			12.4	4.0	18.8	6.6	<0.04	10.95		
31														

TABLE A-17. DAILY ANALYTICAL DATA
July 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		BOD_5(T-un.)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	113	23	18	9	259	38	56	30	176	38	155	14	105	24
2														
3														
4														
5	97	22	32	11	167	38	88	30	232	8	152	7	92	26
6	151	33	23	15	265	43	64	32	205	43	179	18	126	33
7	97	22	20	2	296	41	47	24	204	59	195	58	101	24
8	117		27		258		52		332		324		133	
9	128	21	31	9	283	41	76	28	300	55	275	53	133	21
10														
11														
12														
13									252	26				
14	76	20							115	36				
15	87	23							119	9				
16	97	22							135	11				
17									160	9				
18														
19	156	30							433	32				
20	104	23							180	28				
21	173	25							367	25				
22	136	14							277	13				
23	80	25							162	21				
24														
25														
26	73	30							139	19				
27	140	21							268	16				
28	155	31							465	31				
29	92	38							288	43				
30	132	25							359	29				
31														

(continued)

TABLE A-17. (continued)

Date	Ortho-P		Tot. P		Tot. P (S)		NH_4-N		TKN		NO_3-N		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	2.16	1.29	6.01	1.52			9.4	2.5	16.5	5.2	0.23	8.78		
2														
3														
4														
5	2.34	0.69	4.21	0.81			14.0	4.6	23.5	6.6				
6	2.17	0.68	4.65	0.93			8.6	5.7	18.0	8.6				
7	2.36	0.59	3.03	0.72			7.4	2.5	13.9	4.6				
8	2.47		4.02				9.5		16.1					
9	2.82	0.55	4.86	0.73			11.5	4.2	21.5	5.9				
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE A-18. DAILY ANALYTICAL DATA
August 1981

Date	BOD$_5$ (T)		BOD$_5$ (S)		COD (T)		COD (S)		SS		VSS		Fe (T)	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	75	26							215	49				
2	103	43							252	35				
3	128	39							253	48				
4	101	13							221	41				
5	71	15							186	34				
6														
7														
8														
9	104	9							690	40				
10	73	13							238	48				
11		15								22				
12	129	27							300	31				
13	110	25							267	41				
14														
15														
16	94	23							267	24				
17	74	23							182	32				
18	87	26							248	34				
19	64	18							129	25				
20	212	26							1320	48				
21														
22														
23	97	15							165	7				
24	146	23							430	31				
25	153	30							560	85				
26	110	15							245	13				
27	236	28							990	33				

APPENDIX B

DAILY DUPLICATE ANALYTICAL DATA

Notes: All values in mg/l.
T = Total
S = Soluble
Analyses performed from August 1980 to April 1981 by the Ithaca Wastewater Treatment Plant Laboratory.
Analyses performed from June 1981 to August 1981 by Eco Technology Mobile Laboratory.

TABLE B-1. DAILY ANALYTICAL DATA
August 1980

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3										37				
4										5				
5										35				
6										30				
7										31				
8														
9														
10										32				
11										45				
12										18				
13										17				
14										23				
15														
16														
17										44				
18										18				
19	137	24								7				
20	94	28								19				
21	120	22								23				
22														
23														
24	67	23								14				
25	154	57								43				
26	127	74								86				
27	37	31								29				
28														
29														
30														
31														

TABLE B-2. DAILY ANALYTICAL DATA
September 1980

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1										44				
2	67	30		5						50				
3	136	64								52				
4	82	12		5						12				
5														
6														
7	86	22		3						72				
8														
9	47	40		3						12				
10	265	36		6										
11	200	40		4						44				
12														
13														
14	49	26		4						88				
15	140	24		3						48				
16														
17	160	30												
18	144	42		2						72				
19														
20														
21	249	35	23	2						21				
22	270	63	23	3						88				
23														
24	194	38	20	4										
25														
26														
27														
28														
29	318	50		4						92				
30														
31														

TABLE B-3. DAILY ANALYTICAL DATA
October 1980

Date	BOD_5 (T) Inf.	BOD_5 (T) Eff.	BOD_5 (S) Inf.	BOD_5 (S) Eff.	COD (T) Inf.	COD (T) Eff.	COD (S) Inf.	COD (S) Eff.	SS Inf.	SS Eff.	VSS Inf.	VSS Eff.	Ortho-P Inf.	Ortho-P Eff.
1	340	65								96				
2	200	56												
3														
4														
5	163	51		5										
6	208	25								40				
7	169	33								32				
8	218	30												
9										28				
10														
11														
12	109	23								42				
13	175	25								12				
14	155	36								32				
15														
16	310	49								40				
17														
18														
19	252	39								38				
20	202	64								100				
21										100				
22										58				
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE B-4. DAILY ANALYTICAL DATA
November 1980

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9	142	13								28				
10	125	30								30				
11	131	54							252	125				
12	131	34							234	48				
13	150			4					110	43				
14														
15														
16	120	39							100	32				
17	131	43							120	37				
18	159	66							174	44				
19	129	44							136	26				
20									122	19				
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE B-5. DAILY ANALYTICAL DATA
December 1980

	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P	
Date	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	95	48							118	22				
2	162	40							136	14				
3														
4														
5														
6														
7	240	61							158	49				
8	312	88							344	39				
9	196	60							120	32				
10	150	46							118	31				
11	482	53		8					98	20				
12														
13														
14	192	128							126	122				
15	288	81							134	63				
16	272	42							134	22				
17									144	47				
18									116	32				
19														
20														
21	104	49							138	37				
22	152	53							136	50				
23	179	51								44				
24	147	41							84	16				
25	78	39							52	13				
26														
27														
28	104	45							84	26				
29	122	33							144	32				
30	152	47												
31	111	24							92	11				

TABLE B-6. DAILY ANALYTICAL DATA
January 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	96	23		5					61	16				
2														
3														
4	120	47							65	32				
5	133	42							86	25				
6	130	44							134	35				
7	117	37							91	19				
8	119	67							183	57				
9														
10	94	62							130	61				
11	132	51							44	15				
12	165	74							106	50				
13	100	68							77	38				
14	119	35							146	21				
15	111	43							119	15				
16														
17														
18	94	16							71	17				
19	15	2							127	27				
20	128	44							145	14				
21	126	68							79	60				
22														
23														
24														
25	153	17							216	44				
26	56	13							74	34				
27									266	57				
28														
29									126	61				
30														
31														

TABLE B-7. DAILY ANALYTICAL DATA
February 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19	131	49							86	13				
20														
21														
22	92	28							70	31				
23														
24	93	23							130	36				
25	103	19							132	19				
26	68	34							142	59				
27														
28														
29									160	25				
30														
31														

TABLE B-8. DAILY ANALYTICAL DATA
March 1931

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	98	37							160	25				
2	155	39							246	39				
3	102	29							108	30				
4	136	31							172	43				
5	119	15							268	29				
6														
7														
8														
9	124	40												
10	120	36							302	51				
11	135	58							154	36				
12	135	23							176	28				
13														
14														
15									306	37				
16														
17														
18														
19														
20														
21														
22														
23														
24	192	82												
25	209	77							186	78				
26									138	67				
27														
28														
29	162	38							320	72				
30	144	17							250	36				
31	116	79							236	54				

TABLE B-9. DAILY ANALYTICAL DATA
April 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	189	33							184	38				
2	86	16							144	38				
3														
4														
5	96	50							224	35				
6	210	25							362	25				
7	154	32							244	27				
8	154	25							102	44				
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														

TABLE B-10. DAILY ANALYTICAL DATA
June 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P		NH_4-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	123	11	44	3	503	90	125	82	402	44	248	30	3.50	2.10		
2	88	8	36	3	368	82	137	51	338	20	191	12	2.70	1.50		
3	105	15	32	3	286	86	82	47	191	14	126	10	3.00	1.20		
4	110	12	18	3	341	74	145	47	222	18	170		2.10	0.93		
5	115	11	23	3	372		113		219	15	157		1.20	0.28		
6	84	10	12	2	274	67	82	43	183	17	142	15	2.10	0.44		
7	102	10	21	5	293	55	90	55	191	19	106	9	2.20	0.59		
8	135	12	26	3	350	63	86	51	228	24	169	12	2.50	0.87		
9	131	11	17	2	300	65	71	42	251	12	170	9	2.60	1.78	9.1	8.1
10	90	13	23	2	189	48	64	39	157	22	111	18	1.15	0.60	5.4	4.8
11	52	16	15	3	258	70	102	46	127	12	80	12	0.89	0.68	7.6	4.8
12	48	10	19	2	106	35	48	16	77	14	51	12	1.35	0.72	8.4	8.2
13			79	2	81	27	39	10	43	18	42	13	1.48	1.14	8.2	7.6
14	61	19	20	2	175	42	62	29	139	20	81	11	0.89	0.67	8.0	5.6
15	70	25	25	3	215	50	113	15	125	42	98	14	0.86	0.54	3.4	2.2
16	94	25	19	2	273	42	50	14	215	24	140		1.03	0.42	4.8	3.2
17	141	21	31	3	369	54	62	46	272	54	183	32	0.60	0.12	20.0	10.5
18	97	23	32	4	212	54	62	31	122	28	76	26	0.99	0.07	12.0	8.6
19	88	21	31	5	239	64	62	40	112	19	105	13	1.29	0.21	9.0	6.0
20	56	15	40	9	146	87	39	42	96	51	58	33	1.30	0.56	9.3	7.3
21	232	22	17	1	281	65	52	29	150	26	100	20	1.61	0.04	11.0	6.6
22	133	24	26	3	347	78	49	10	194	22	30	8	1.13	0.11	5.0	2.3
23	99	26	15	2	297	78	80	25	177	25	52	23	1.35	0.22	18.1	4.4
24	98	30	25	2	256	62	62	19	236	80	20	18	1.13	0.04	7.1	4.8
25				1	391	74	64	33	214	27	68	11	0.86	0.05	10.0	4.8
26	44	14	12	4	124	66	18	8	84	19	26	7	1.02	0.07	10.5	6.2
27	55	19	12	4	96	46	42	18	63	28	28	9	1.37	0.62	5.5	2.6
28	41	23	10	3	159	59	84	19	75	33	23	15	1.33	1.01	8.3	3.6
29	65		10	1	168	53	50	23	133	27	9	8	1.05	0.84	8.8	2.1
30	36	17	12	7	198	65	72	34	123	25	34	8	1.47	0.77	10.1	4.6
31																

TABLE B-11. DAILY ANALYTICAL DATA
July 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P		NH_4-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	89	20	16	4	278	55	88	6	107	48	32	34	1.32	1.02		
2	78	10	9	1	339	16	31	6	233	16	68	5	1.21	0.48	5.1	1.4
3	141	28	27	5	273	47	59	21	159	26	35	11	1.26	0.73	8.1	4.2
4	111	28	17	4	180	43	51	24	129	41	20	14	1.15	0.83	8.2	5.8
5	135	26	19	5	238	29	53	20	180	27	70	13	1.28	0.65	11.3	4.9
6	149	35	29	5	275	58	75	35	157	19	54	5	1.67	0.66	5.5	3.5
7	135	13	29	3	248	24	67	13	122	23	69	13	1.42	0.48	7.2	3.0
8	152		25		309		54		211		173		1.50		7.2	3.0
9	134	23	25	3	289	39	29	17	246	13	160	8	1.31	0.41	5.2	2.4
10	185	21	25	3	379	42	39	33	218	15	171	12	1.63	0.36	7.8	3.6
11	101	22	13	2	316	81	39	19	134	32	101	21	1.54	0.41	8.8	3.8
12	275	35	29	4	810	86	80	50	184	36	127	23	1.45	0.23	9.8	4.5
13	133	43	33	3	321	95	73	28	149	52	111	33	1.79	0.11	7.6	4.5
14	119	19	23	3	271	53	53	32	157	14	109	10	1.36	0.05	5.7	1.7
15	119	22	18	3	323	32	40	18	157	19	111	13	0.77	0.11	7.4	4.2
16	146	18	18	3	384	40	42	16	230	15	178	11	1.40	0.30	7.4	2.2
17	163	20	31	2	588	46	72	20	426	14	248	10	1.40	0.47	8.8	4.8
18	178	21	18	3	542	68	56	28	367	17	246	11	1.33	0.24	7.9	4.0
19	146	12	39	2	463	52	58	38	321	30	220	22	1.51	0.27	4.1	1.7
20	87	22	18	2	268	44	72	34	157	14	33	7	0.80	0.23	3.0	1.1
21	176	20	22	12	386	48	56	16	295	12	207	11	1.20	0.07	3.1	1.4
22	147	10	10	1	432	25	98	18	267	9	153	5	0.60	0.05	4.4	1.0
23	97	26	14	3	248	41	73	20	166	25	72	17	1.39	0.20	5.1	1.7
24	111	21	17	3	345	27	87	24	221	26	139	17	1.16	0.62	7.4	2.6
25	170	8	12	2	679	22	20	12	682	12	392	9	0.66	0.03	12.1	2.9
26	108	23	18	5	269	54	51	38	173	30	119	17	1.18	0.08	6.5	1.6
27	142	21	14	2	354	46	48	31	265	17	187	12	1.02	0.05	22.0	3.8
28	203	35	18	2	454	54	48	23	434	27	262	19	1.02	0.78	9.7	6.8
29	111	42	13	2	228	50	34	19	235	43	152	26	0.52	1.78	19.5	8.8
30	147	29	17	3	400	29	38	13	332	25	214	16	1.22	1.39	10.0	7.8
31	133	19	8	1	406	42	52	11	309	24	186	11	0.76	0.20	9.8	4.6

TABLE B-12. DAILY ANALYTICAL DATA
August 1981

Date	BOD_5 (T)		BOD_5 (S)		COD (T)		COD (S)		SS		VSS		Ortho-P		NH_4-N	
	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.	Inf.	Eff.
1	124	15	14	2	293	42	57	19	228	15	176	10	1.37	0.73	11.8	1.4
2	123	32	13	3	272	74	53	36	201	39	137	24	1.20	1.51	9.4	2.0
3	134	27	11	6	289	57	53	23	228	28	137	18	0.63	1.22	21.8	6.6
4																
5	102	17	13	1	279	32	42	27	217	30	150	18	0.44	0.31	6.8	<1.0
6	121	20	17	1	289	65	44	30	97	30	57	16	0.80	0.44	7.8	<1.0
7	87	15	15	2	255	34	38	23	122	19	89	14	0.84	0.40	8.1	<1.0
8	84	12	13	1	224	47	50	23	119	23	83	15	0.69	0.38	7.2	<1.0
9	126	8	15	2	479	27	42	15	358	14	230	10	0.44	0.38	8.6	<1.0
10	120	15	14	3	477	42	33	19	228	19	150	15	0.49	0.21	6.8	<1.0
11		15		2		45		11		18		12		0.33		<1.0
12	121	26	14	2	372	25	15	4	339	35	184	20	0.52	0.17	12.9	3.3
13	103	24	9	2	323	41	21	36	340	42	183	22	0.44	0.18	13.2	4.1
14	83	25	11	3	267	55	29	34	190	38	114	17	0.61	0.24	6.6	2.5
15	106	16	12	1	268	51	46	36	235	17	146	11	0.73	0.13	9.6	3.4
16	90	21	12	4	230	48	23	23	199	37	145	26	0.37	0.24	6.7	2.0
17	107	19	12	2	310	47	57	36	246	22	148	11	0.70	0.15	8.3	3.1
18	71	17	14	2	225	47	43	32	179	23	112	14	0.72	0.11	10.0	3.9
19	79	16	9	2	234	45	36	26	171	23	104	11	0.85	0.09	7.6	3.0
20	274	19	17	4	1050	104	51	32	1190	53	600	27	0.31	0.08	1.3	4.0
21	126	11	48	2	455	85	44	45	410	48	232	23	0.40	0.08	9.7	4.2
22	109	10	8	2	273	51	36	36	229	20	152	11	0.72	0.17	14.6	4.1
23	127	25	15	2	344	53	36	17	293	23	178	12	1.84	0.19	8.9	2.9
24	151	22	11	3	668	53	51	38	552	34	277	13	0.52	0.11	11.9	11.0
25	167	27	15	2	593	76	40	29	482	71	285	37	0.85	0.22	6.2	2.4
26	163	18	21	2	329	25	49	17	265	15	156	7	0.95	0.75	8.7	2.8
27	348	32	18	3	945	46	48	19	991	41	564	17	0.40	0.41	13.2	6.5
28																
29																
30																
31																